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TELECOMMISSION STUDY

4(a)

THE FUTURE OF COMMUNICATIONS TECHNOLOGY

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FOREWORD

This study expresses the views of individuals, groups of individuals or the concerted views of organizations in the technical areas in which they are most knowledgeable.

The different contributors do not necessarily agree on all detail or wholly support each other's views. It has, however, been possible to draw out some general conclusions and to provide a good deal of detailed technical opinion in each of the areas.

Formal submissions to Telecommission Study 4(a) were received from the following organizations:

1. The Electronic Industries Association of Canada.

2. The Trans-Canada Telephone System.

Requests for copies of a supporting brief should be directed to the source of the brief.

This Report was prepared for the Department of Communications by a project team made up of representatives from various organizations and does not necessarily represent the views of the Department or of the federal Government, and no commitment for future action should be inferred from the recommendations of the participants.

This Report is to be considered as a background working paper and no effort has been made to edit it for uniformity of terminology with other studies.

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ACKNOWLEDGEMENTS

The Bell Canada contributions to the common carrier portions of the Study reflected the generally agreed technical views of the Trans-Canada Telephone System. The EIAC contributions are representative of that organization.

A good deal of credit for individual contributions is due to the staff and associates of the members of the Study. They were instrumental in the preparation of many contributions. For example, specialist sub-groups met to prepare the studies on Basic Technology.

On occasion, information on specific subjects was solicited from individuals or organizations not participating directly in the study. Their views were most helpful.

CONTENTS

1. INTRODUCTION

GENERAL

The Telecommission owes its existence to the explosive rate of change in the technology of communications and to concern over the effects on Canadian life. This particular Study concerns itself with this technology in meeting our future needs.

New or improved technology can have a manifold impact on communications. This can be through reduction of costs of providing old services, through improved services, through better integration of services, through improved maintenance etc., and through the introduction of new services.

The introduction and the penetration of new services are the most difficult to predict since they depend on many factors. These obviously include the attractiveness, the price, the capital tied up in existing services, the willingness of the consumer to accept and pay for them and the inventiveness of mankind. Also, existing competing methods do not usually stand still and a new service or technique must compete with versions of the older ones that are also being improved by new technology.

STUDY PLAN

The sheer size of the activity covered by the term communications creates a problem. It was not possible for the study team to cover in any useful way all of the relevant technical developments currently appearing. It is also intrinsically impossible to consider the future surprises that experience has taught will appear. Consequently the Study Group has confined itself to looking at certain important major areas of communications in which technological change is likely to have the greatest impact upon our society. The approach taken was to successively consider:

(1) The future environment in these areas—or in broad terms, what the Study Group foresees as being needed or wanted within the time scale defined for the study,

(2) the basic technologies considered most important in these areas and what might be expected from them for application in the periods considered,

(3) the impact of the new technological developments on the important elements of these areas of communication,

(4) the systems implications or how the advances can or will affect the overall systems or areas considered,

(5) conclusions that can be drawn from the technical considerations.

The contributions to a technical study are necessarily detailed. In consequence an attempt has been made to draw out the major thrusts, trends and facts in the body of the report.

Looking to the future is always hazardous and different members of the Study Group look through their own crystal balls. For many reasons crystal balls cannot be expected to mix and as might be expected, contributors sometimes hold differing views on trends and timetables. More complete position papers submitted by individuals, organizations, or groups are appended.

DEFINITION OF TERMS

When specialized technical or system terms are used an attempt has been made to define them when they are first introduced. However some of the essential and commonly used terms are defined here.

General Terms

Communications generally means the transmission or interchange of information. It is usually used in this study in preference to the narrower term *Telecommunications* that is usually used for communications by electromagnetic means.

Technology is the term usually applied to all facets of applied science that have commercial value or foreseeable use. In this study reference is made to *Communications Technology* and the effect on it of newer technologies or developments. The new things can be new components, new circuitry techniques, new concepts of transmission, new equipments and completely new approaches, etc.

Radio Terms

Broadcasting refers to one-way communication using electromagnetic propagation in free space in the restricted sense of mass communications.

Diffusion is the process of delivering signals (such as mass communications) directly to individual recipients. It may refer to Broadcasting systems as defined or to guided systems such as community antenna cable systems (CATV).

Distribution is the process of delivering information to diffusion centres from which it can be diffused to the recipients.

Common Carrier Terms

Toll Calling	- All calls outside of local calling boundary which are subject to charges above monthly charge.
Direct Distance Dialing	- direct dialing ability for Toll calling.
Local Calling Boundaries	- all telephones which can be reached on monthly flat rate (no additional toll charges).
Abbreviated Dialing	- a service which allows selected numbers to be dialed with two or three digits.
Automatic Recalling	- ability to redial automatically the last number which was previously dialed manually.
Conference Calling	- a means of adding additional people on to a normal two station call.
Wired Music	- a special music distribution system provided on wire lines.
Radio Program Services	- audio facilities for inter-broadcaster transmission.
Video Program Services	- video facilities for inter-broadcaster transmission.
Videophone	- a visual telephone for two-way communication.
Distribution Facilities	- transmission facilities between customers and end switching office.
Trunking Facilities	- transmission facilities between switching centres.
Local Switching Centre	- the end switching centre which connects to a customer.
Tandem Switching Centre	- a switching centre which switches switching centres to switching centres.
Inter-Office Call	- a call between two customers in different local switching centres.
Intra-Office Call	- a call between two customers in same local switching centre.
Signalling and Supervision	- the signals necessary to select and hold a transmission path.

TIME SCALE

The study is intended to embrace 1970 to 1990. Where general estimates of the time of implementation (introduction into service) are made, the 20 year period is divided into four equal five year intervals.

2. THE FUTURE ENVIRONMENT

GENERAL

Much has been written about the new communications environment in which a wide range of new services has become technically possible. Not only is a great diversity of services foreseen but a period of tremendous growth.

It is widely recognized that some of these services will have a profound impact on our family and community life and on business and industrial organization of the country. It is also evident that the telecommunications service and manufacturing industries "must provide the essential infra-structure" upon which the "communications explosion" or "information industry" is built.

It is the intent in this section to consider the broad trends, possibilities and anticipated demands of the Canadian environment as seen by technical people involved in major areas of communications.

2.1 COMMON CARRIER NETWORK

Trends—Past and Future

The purpose of this part of the report is to review past developments in the expansion of telecommunications services throughout the Canadian common carrier network, and to speculate on the broad trends of future developments. The specific implications of these trends on the common carrier network are treated in other Telecommission Studies as well as Section 5 of this report. It is evident that over the last decade there has been a very marked increase in the number of services carried over the network as well as an ever widening variety of new services available to the customer. Hence, in reviewing the developments in telecommunication services over the last few years it is also evident that the present day network requirements and operations are markedly different to those of ten to fifteen years ago.

In the mid-fifties the network carried primarily voice type services (man-to-man, two-way audio communications) with a secondary component of slower speed services such as telegraph and control systems (machine-to-machine, coded communication). In the latter part of the decade the network was expanded to carry network television signals; that is, it was expanded to carry a man-to-man, one-way visual communication service.

The sixties were characterized by the expansion of data communications[1], with emphasis on increasing speed, to complement the lower speed services as the decade progressed, and towards the end of the decade planning had commenced for the introduction of videophone[2]. The latter service, when introduced within the next few years or so adds the dimension of two-way visual capability to the man-to-man communication spectrum.

Hence, in retrospect, the scope of communications carried over the network has evolved, in a 15 year or so period, from a two-way audio capability to an audio/visual[3] capacity complemented by a wide range of machine-to-machine interaction services permitting high rates of information transfer.

This trend in the expansion of man's communication space over distances will obviously continue with the technological developments that are presently emerging in telecommunications research, to permit man's senses (including those of touch, taste and smell) to be conveyed electromagnetically over network facilities. It is important to recognize that the element of man's various needs for interaction with his environment is vital to new means of communication. Present network capabilities provide for the easy and prompt access to others through sound communication irrespective of distance and these capabilities are constantly being improved upon in terms of signal quality, connect time, etc. The new challenge is to increase the dimension of man's communication space through devices which permit interaction of all five senses. The ability to devise and market such capabilities is the challenge for global communications of the future.

To facilitate a further review and analysis of service developments it is convenient to categorize the means in which communications are provided today into three broad classifications. (It must be recognized that there is an inherent danger in services classifications since the model we construct of today's capability will not be truly representative of those of tomorrow.) The three categories are:

1) Voice Services

2) Visual Services

3) Data Services.

The first group, the voice category, encompasses the regular telephone type service (the man-to-man audio communication) wherein one person speaks to another over a fixed connection along with the auxiliary telephone service which complements it such as:— conference calling, recorded announcements, assistance calling, etc.

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[1] Transmission of coded information between machines.

[2] Picturephone is a videophone trade name.

[3] A/V — involving both hearing and vision.

This category of service has changed quite substantially in the last decade with the introduction of Direct Distance Dialing, the provisioning of different kinds of terminal apparatus, and improvements to the quality of transmission. But generally speaking these changes are being eclipsed by the introduction and development of specialized services such as those to be found in the business-machine-to-business machine communication.

For the future, an evolution of improvement and sophistication in voice type services is foreseen. The changes to be expected are as follows:

- New and improved types of customer terminal apparatus providing for easier use.
- Improved aesthetics in set design.
- Wider utility. That is, cordless stations, hands free stations, portable stations, etc.
- Improved reproduction of speech.
- Extension to existing local calling boundaries to fit customer community of interest needs.
- Two-way communications on a mobile basis through improved paging services.
- Trend toward message type billing for local service.
- Access to a variety of message announcements and information services.
- Provision of abbreviated dialing, automatic recalling, conference calling and other switching services.
- Provisions for the conveyance of stereo and high fidelity music.
- Studio broadcasting.
- Distribution of wired music and radio program services.

The second group encompasses those service offerings which provide for the transmission and reception of the visual sense. For example:

- Videophone
- Network and private TV including educational and instructional services, computer based program learning, etc.
- Graphic displays.
- Audio visual conferencing.

It is in this area that service developments are so captivating to the imagination, and promise to herald a new era of person-to-person communication over distance. With the gradual establishment of videophone service as the ordinary communication medium, supplanting the present day telephone service, many other wideband services should become relatively easy to institute. It is also the area where

technologies are presently under development and the demands of service criteria are relatively undefined and where substantial changes to the existing network of communication plant will be required before widespread use is available to the public. Furthermore this is a field of operations where developments and new technologies will play a critical role in providing the public with a new dimension to add to the existing shared common communication space. It is very definitely an area of vast promise for improvements to communications, as well as to innovation, expertise, and the expansion of business opportunities of all kinds.

It would appear at this point in time, at the advent of the visual communications evolution, that the development of video service from private to switched network offerings present some of the most challenging demands yet experienced by the communications industry, and one where very substantial growth is possible in the near and medium term (that is, within the next decade).

The third group, the data category, is one that perhaps requires a definition for the sake of clarity. In the telecommunications field, data can be defined as information in electromagnetic form. As a result all forms of telecommunications, whether voice, visual or machine, can be considered as data. However, in common usage, data communications is normally considered as the transmission of information in coded form between machines. It employs the business-machine-to-business-machine services which in the past decade have developed rapidly in both volume and variety of needs. These developments have resulted in the requirement for very specialized transmission qualities, the utilization of new technologies, and flexibility in business management in order to ensure customers a high degree of quality and reliability. The data communications age has undoubtedly precipitated a new order to the previously telephone oriented network. It is an area which is considerably increasing in scope and continually requires improvement to plant quality in order to capture ever widening possibilities for expansion and to satisfy customer needs.

Operational Aspects

The voice services carried over the network require, at this time, the largest share of capital and manpower resources to maintain existing offerings and to provide for growth. However, the technologies associated with the establishment and maintenance of these services are well developed (that is, those associated with transmission, switching, accounting, billing, testing and upkeep of plant) and hence emphasis in this area is seen to lie in the future towards refinements, improvements and variety as compared with the more spectacular innovations anticipated in the visual and data offering avenues of communications.

In contrast to the demand for voice services the market for visual capability has been very restricted; it has developed slowly between well defined geographic regions and on a customer switched network concept. Consequently, it is anticipated that the expansion of video offerings will initiate emphasis on system service concepts with the needs arising for technological innovations in network switching, variety of features for both groups and individual requirements, and the provisioning of

service over a range of facility types, etc. Until this time the provisioning of video capability has required specialized equipment packages, which in turn, require special maintenance skills, special administration facilities, and exacting performance standards. The prevailing relationship of small demand and relatively high cost for visual services is the challenge for emerging and future technologies. With the development of new means of providing visual capability at reduced cost, and with a network of plant providing inherent economies of scale, the demand for video services will increase.

In the near and medium term the communications network can be expected to be extended and adapted to facilitate the introduction of:

- Videophone
- Conference TV
- Instructional TV
- Variety of user oriented service engendered by conference TV for business and committee meetings, political meetings and medical training at a distance.

The emphasis here will require numerous technological developments geared towards the further integration of visual capabilities into the overall network, a reduction in the specialization of circuit connections, ease of maintenance, and uniform service quality. Such is the case in the telephone network today whereby common facilities, both line and switching, carry volumes of voice traffic between widely separated parts with uniformity of service quality and maintenance to effect economies of scale. In summary, there will be a need for technological developments to provide commonly distributed video communications systems of varying grades of resolution.

In the longer term it is anticipated that video services such as videophone, graphic communication devices, three dimensional display systems, digital and graphic retrieval services (such as those allowing access to libraries, educational information, banks, etc.) will become widely available in the home as well as in the business communities. The demands on technology will be extended to encompass on an economical basis the needs for visual capability throughout the entire network, in remote areas as well as in urban areas. Today the demand for facilities capable of visual communications is very largely between and within major metropolitan areas.

It is anticipated that the increasing tempo for data communications, as witnessed over the last few years, will continue. Therefore, the variety of services offered will expand as well as the number required for each individual service. In the short term there appears to be a need for sub-voice grade, voice grade, and wideband offerings to fill the range of possible service concepts envisaged today. Already both individual and large group oriented requirements are emerging as contrasted on the one hand by a single residential meter reading service, and on the other hand by the recently instituted Message Switching Data Service system. Of foremost importance in the development of new data communications services will be the need for various transmission speeds,

short response times for circuit connection, message switching, line switching, retrieval concepts, store and forward operations, uni-directional transmission, and selective band service concepts.

The future application of data communication services is expected to be oriented between the business community in the short and medium term with a gradual proliferation to the home market in the medium and long term.

In the next five years, it is envisaged that data bank services will become increasingly attractive for educational and financial institutions, for the medical profession to aid in medical diagnosis and drug prescriptions, and for business institutions to aid in efficient administration (that is, personnel files, inventories, accounting, payrolls, etc.). It is in this area that the time shared computer services should play an important role incorporating the concepts of information retrieval, store and forward service and duplex operation.

In the 1975 to 1985 period a sophisticated and personalized range of services may well develop to provide a continuing impetus for expansion of data communications. These include:

- The facsimile[4] services for real estate listings, employment services, commercial and sales information, coding of technical papers, educational services, etc.
- The time shared computer services for intellectual and professional assistance.
- Translation.
- Teaching.
- Literature research.
- Traffic control.
- Computational assistance.
- Design and analysis work.
- Meter reading.
- Remote control of household appliances.
- Unattended alarm services.
- Banking, bill paying and budget management.
- Graphic communication devices.
- Copy or print services.
- Remote adding machine, access by the tone dialing telephone set.
- Voice recognition services.

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[4] A transmission-recording system in which pictures or print are transformed into electrical signals very much more slowly than television. It required a very much narrower bandwidth for transmission and the output is printed material.

In the 1980 to 1990 period the continued expansion of data communications is envisaged in the establishment of a wide range of services to the home perhaps via in-house mini-computers.

2.2 BROADCASTING

There are many varied and interdependent factors that are expected to influence the system of broadcasting, that we now know, in the next two decades.

First, there are the monies that will be made available from public funds, and from advertising. Figure 1 shows these monies for the period from 1962 to 1968. Projections based on these data are hazardous. For instance, the effects of the fragmentation of audiences by CATV are difficult to estimate. The availability of these monies will affect the future growth of private TV stations' coverage (second service) which today is about 75% of the English speaking population and 60% of the French speaking population. Coverage of communities still without radio and/or TV primary service is very important; (see Table 1). Because of the small size of these communities, each new transmitter adds only a fraction to the total coverage, while capital and operating costs are relatively high. The objective of installing second language TV outlets will depend upon public funds being available.

Greater demands will be placed on the CBC's operating budget by the eventual completion of the conversion to color TV; at the present time about 65% of all CBC TV programming is in color. Of importance is that the existing method of distributing TV and radio signals by a system of broadcast stations is the least costly.

TABLE 1

CBC Coverage in Canada — Radio and Television
English, French and Composite Networks — Estimates as of March 31, 1969

	Population that speak English		Population that speak French		Total population	
	16,820,000		6,520,000		21,020,000	
	English Network Coverage		French Network Coverage		Composite Networks Coverage	
	Number	Percent of total	Number	Percent of total	Number	Percent of total
Radio (AM)	16,570,000	98.5%	6,310,000	96.8%	20,780,000	98.9%
Television	16,050,000	95.4%	5,850,000	89.7%	20,360,000	96.9%

NOTE: The statistics are based on the service areas (radio.. daytime service, television.. A & B service) of all CBC-owned and CBC-affiliated stations in operation or recommended for approval by the BBG prior to April 1, 1968.

Source: CBC Annual Report 1968/69.

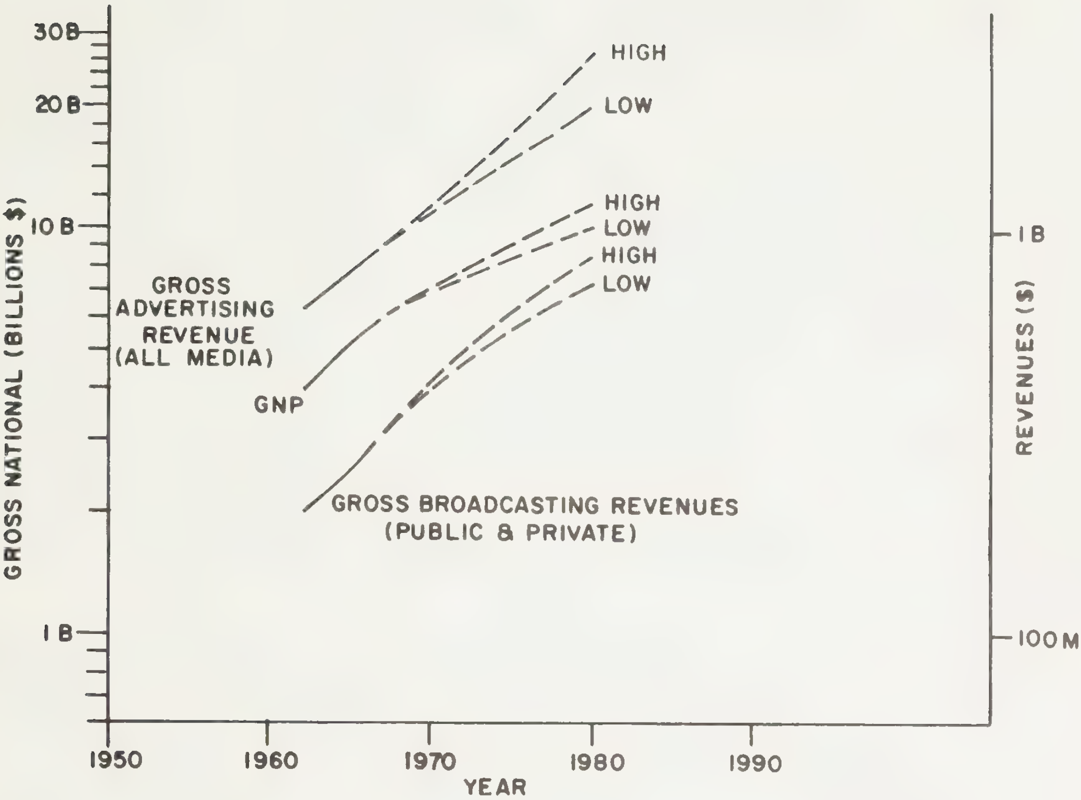

Fig. 1. Revenues in Dollars.

Source—D.B.S.; CBC Annual Report

Second, there are the population growth and shifts. The shift to towns is well known. However, if such imaginative projects as the Central Canada corridor should come to pass, it cannot be assumed that the towns to which the population is drifting will necessarily remain the same as now. Hence, coverage requirements will change.

Third, there are the technological changes, which are discussed in more detail in Section 5.3. New technological developments that are likely to have an important impact on broadcasting in the next 20 years are cable distribution systems (CATV), home audio/visual playback systems, space satellites, and solid state electronic devices. The effect of these new technologies will be to provide a much greater diversification of program content and services, at a cost low enough and a quality high enough to generate new mass markets.

Fourth, there are the social and political factors. Second TV service, in areas not now getting it, becomes more and more difficult and expensive to supply as coverage increases, and growth of the second service is likely to depend upon political rather than economic pressure. The growth of cable systems outside the areas in which they now exist depends upon the CRTC microwave policy rather than economic factors.

The growth of cable systems outside the areas in which they now exist depends upon the CRTC microwave policy rather than economic factors. The growth of cable systems, in the long view, depends upon society's demands for more services which only cable systems can provide. For example, a future cable service might include 20 or more TV channels with separate educational, local affairs and information channels; it might provide facsimile read-outs (of first class mail)[5]. The future of broadcasting through free space, as we now know it, will eventually be determined by society's demands for the particular advantages that broadcasting offers, for example, a service to mobile audiences, a service to rural areas, and a free service to those who are not prepared to pay the cable system charges. It does not appear possible to provide large numbers of TV channels (20 or more) to most viewers through normal over-the-air broadcasting means with the existing system of broadcast stations and the lack of available spectrum. An example of a political question that might be faced in the near future is as follows: the projected first domestic satellite, in combination with a cable system, could conceivably make the French language TV service available in Vancouver before the CBC is ready to install a transmitter there. Should viewers in Vancouver wishing to watch French TV be forced to pay as cable system subscribers?

Fifth, there are consumer expenditures on broadcast receivers and related services. Figure 2 shows households with broadcast receivers from 1952-68. Figure 3 shows the number of TV and radio sets in operation during the same period. Figure 4 shows consumer expenditures on broadcast receivers for each year from 1963-68. Predictions of future growth are hazardous because of the many claims on the consumer dollar, including automobiles, vacations, hobbies. Furthermore, prediction is doubly difficult because new developments in communications technology offer the prospects of a wide range of new services, but it is far from certain that the public is prepared to pay for them. At the present time some 1,000,000 homes in Canada are paying five to six dollars a month for the advantages of a cable system service. This gives annual gross revenues of 60 to 70 million dollars. It has been suggested[5] that a 'national grid' of cable systems can replace the first class mail service, reduce travel and generate a much larger proportion of the gross national product (GNP) than broadcasting does today. In the foreseeable future, consumer expenditures are likely to make a considerable contribution to:

1) the growth of cable systems,
2) the growth of multi-receiver households,
3) the growth of color TV households,
4) the growth of FM households,
5) the growth of households with audio/visual playback units.

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[5] EIA filing of FCC docket 18397, Part V.

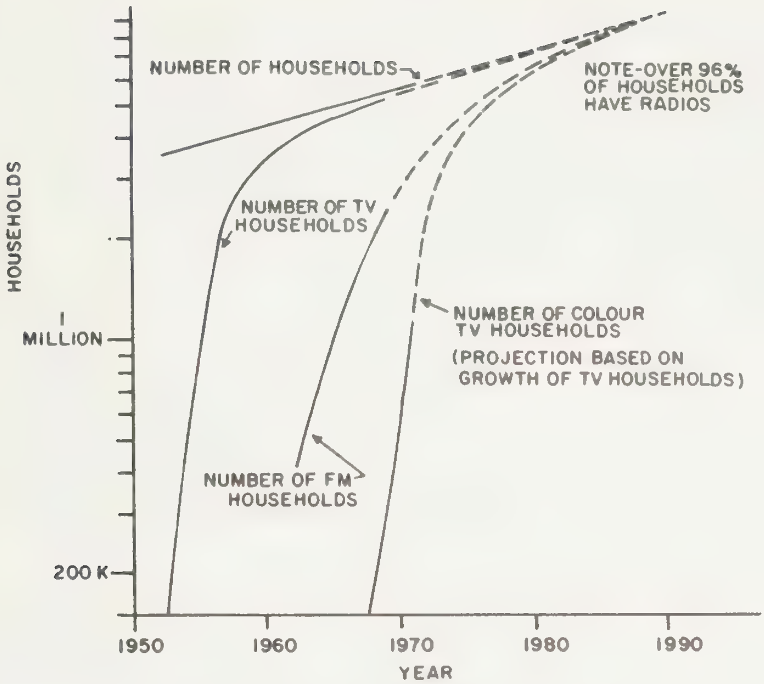

Fig. 2. Households with Receivers.

Sources: D.B.S.,
Economic Council of Canada,
CBC Annual Reports,
EIA of Canada.

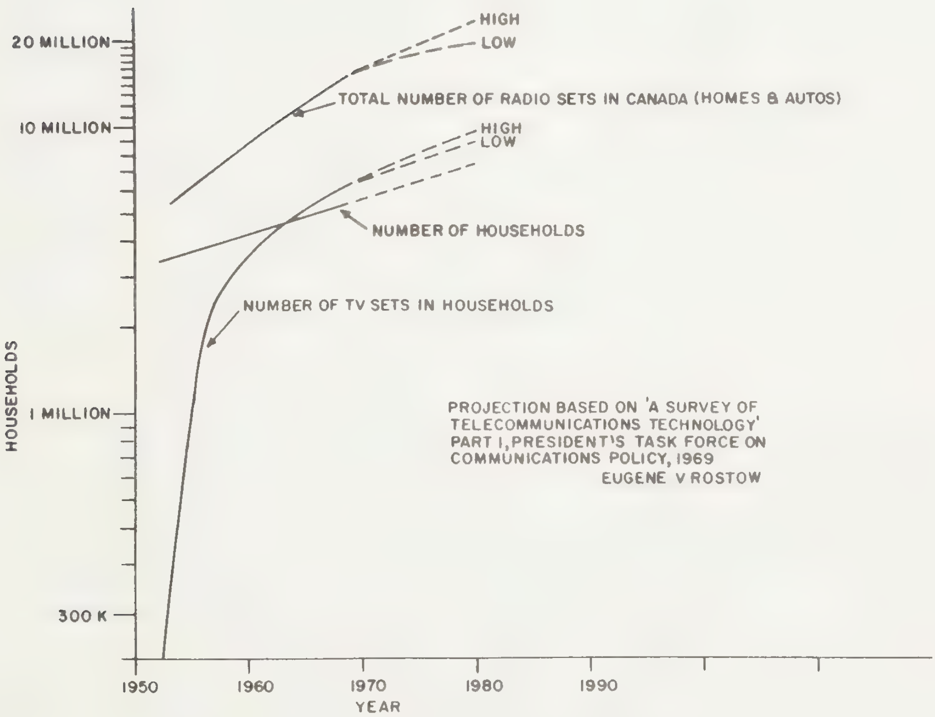

Fig. 3. Total Radio and TV Sets.

Sources: Economic Council of Canada
A.C. Neilson Survey
D.B.S.

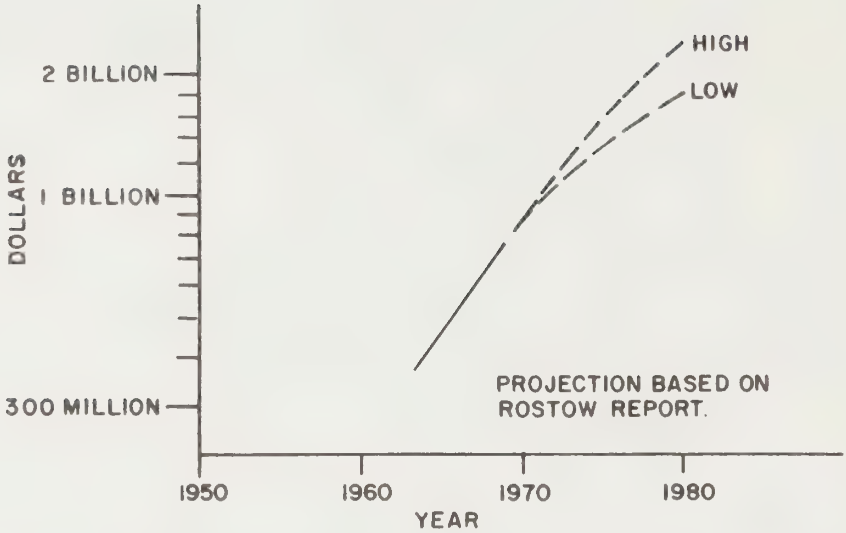

Fig. 4. Consumer Expenditures for Radio and TV Receivers.

Source: Canadian Electronics Engineering.

Note: Factory Sales in \$ × factor of 3.

2.2.1 Cable Systems (CATV)

The recent spectacular growth of cable systems warrants particular mention. Figure 5 shows the growth of subscribers to cable TV in Canada from 1964-1969. Some 19% of all viewing in Canada is by cable today.

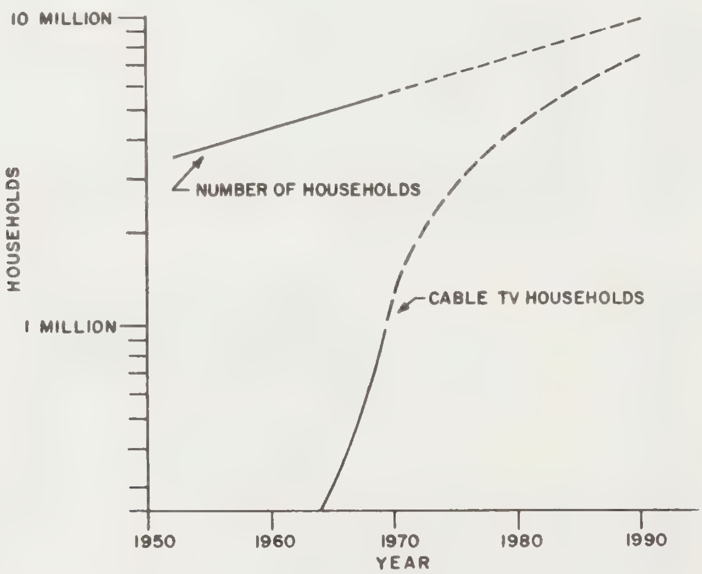

Fig. 5. Cable TV Growth.

Sources: CRTC,
A.C. Neilson Survey.

Table 2 gives cable viewing in Canada by province in an average week of March 1969.

TABLE 2

Cable TV in an Average Week

	March 1969	
	Number	Percentage
Canada	3.10 million	15.9
Newfoundland	1,000	0.2
P.E.I.	-	-
Nova Scotia	5,000	0.7
New Brunswick	46,000	7.8
Quebec	890,000	15.8
Ontario	1,293,000	18.7
Manitoba	46,000	5.2
Saskatchewan	22,000	2.5
Alberta	46,000	3.3
British Columbia	746,000	39.8

Source: CBC Research; 2nd Cable Report, October 1968.

However, growth of the number of cable subscribers is not uniform across the country; in London, Ontario, 76% of all viewing is by cable, whereas in Chatham, Ontario, only 14% is by cable. The main stimulus for cable systems is undoubtedly the desire to get U.S. stations, for English speaking viewers, and the desire to get Montreal stations, for French speaking viewers. Thus, the main growth of cable systems has been in Southern Quebec, Southern Ontario and Southern B.C. Should the CRTC allow the importation via microwave of U.S. network stations beyond the near border cities, then cable systems can be expected to become available to all Canadian cities of 10,000 people or more within the next decade. Table 3 shows that cable systems would then be available to nine million viewers outside Quebec and 3.8 million inside Quebec, giving a potential viewing population of 12.8 million. This development would have a profound effect on the present system of broadcast stations, whose role would change to satisfy a mobile and a rural audience.

The monies available to broadcasting would likely be diverted in part to the cable systems, particularly if, as in the USA from January 1971, advertising is allowed on cable systems. Demands for program origination are expected to increase as the diversity and usage of the cable services increase. The likelihood is that a growing proportion of the programs will be connected directly to cable systems rather than through off-air reception.

The satellite-cable system combination is particularly promising as a means of building a 'national grid' of cable systems with the possibility of making connections to all communities, large and small, of Canada.

TABLE 3

Urban/Rural Population of Canada, 1966

	Outside Quebec	In Quebec	Total
Cities of 10,000 plus	9.0 million	3.8 million	12.8 million
Cities of 1,000-10,000	1.7	0.6	2.3
Rural	4.0	1.3	5.3
TOTALS	14.7	5.7	20.4

Source: Canada Year Book, 1968.

2.3 MOBILE COMMUNICATIONS

Electromagnetic communication with moving vehicles started in the marine field. Since then, mobile communications has become an indispensable adjunct to land, air and marine operations.

The types of communication range from manual morse, voice and video, to high speed data. Portable communicators now also include directed millimeter and laser devices.

The advances in technology, techniques, data systems, etc., are applicable to the mobile field and are opening the possibility of greatly improved and expanded services and of new system concepts.

2.3.1 Marine Mobile Communications

Marine communications are intimately linked with navigation, traffic control and maritime operational services. Key major areas for technical development are considered to include:

- Automatic warning of collision course
- Approach traffic control
- Ship-to-shore-to-ship communications
- Bridge-to-bridge communications
- Determination of positional accuracy.

The varied needs of ship-shore-ship communications will be met by ground wave and ionospheric propagation for another 15 to 20 years.

There will be expansion of the public correspondence services so that all ships within 60 miles of most Canadian territory should be able to communicate via VHF. Channels will be provided for radio-telephony, radio-teletype and data. All major Canadian ports will provide navigation information service via radio telephone.

In the 1970-75 period, area surveillance systems based on transponders will be introduced for marine traffic control, (probably initially on the St. Lawrence River). Maritime radar beacon transponders

will be installed (up to 10 per year between 1970 and 1980) covering all Canadian coastal waters. Harbour radar installations and associated microwave data gathering links will also be installed.

In the 1975-80 period, ice and weather map service from satellites will be available on a dedicated VHF or UHF channel.

Arctic maritime communications services will be extended and improved. In particular, the service providing ice and weather information into the Arctic by HF facsimile will be expanded.

A primary motive for the introduction of new technological developments by maritime interests will be elimination of shipboard human effort. This is a strong factor in the introduction of developments as selective calling[6], direct printing, automatic alarm (for collision course), automatic access to Telex, AQR[7].

The use of GHz frequencies with automatically directed antennas for line-of-sight ship-to-ship communications and for traffic control etc., will develop rapidly.

Earth satellite systems will revolutionize marine communications, navigation and position determination. They will improve service, dependability, accuracy and increase coverage. If they result in large ships saving a day's time the economies would be considerable. However, spectrum utilization problems will be severe. Inter-coast station trunking systems would probably be needed. Present international indications are that the development of satellite systems for marine purposes will be slow and such service will not be available until the 1980-1990 decade. Such satellite systems would not be generally useful for small ships.

Offshore exploration and production activity could provide considerable impetus to the development of satellite systems because of the requirements for precise position location. Satellite systems are particularly attractive for positioning at long distances from the shore line and for periodically checking medium distance systems that may be subject to propagation errors introduced by ice, etc.

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[6] Systems where the shore transmitter sends out signals on a number of carriers and the ship-borne transceiver automatically signals the optimum frequency for communication. Information on the ratio of signal to interference at the shore station can also be sent in digital code to aid the automatic choice.

[7] Automatic request and repeat coding, a system that automatically requests repeat transmission on the basis of error content.

2.3.2 Air Mobile Communications

Background

The initial use of air-to-ground radio communications was for the purpose of enroute checking of flight progress and instructions for take-off and landing. The rapid increase in air traffic (particularly of a commercial type) and the increase of speed of travel over the past 30 years, has made it necessary to augment voice communications by other means. More sophisticated means for navigation and position location have accelerated the development of navigation aids. These aids have progressed from the stage of being a supplement to voice communications to the stage of being dominant factors in their own right. There is less and less dependence on voice communication and an ever-increasing need for the transfer of coded high-speed data.

New and more sophisticated navigation, recording and control systems are, and will be, introduced which will greatly expand the need for the transfer of many types of intelligence.

Anticipated Demand

Air traffic is Canada's and the world's, fastest growing means of transportation. Recent studies in the United States and the United Kingdom indicate that the rate of aviation activity existent in 1968 will be at least doubled by 1980 and doubled again by 1995. This means that aircraft will have to take off, fly and land much closer together. The increased size and speed of aircraft brings about the contradiction that for safety the aircraft should fly much further apart. The only solution to this anomaly which will bring about an improved situation, is to greatly increase the accuracy, reliability and speed of response of the navigation and communication equipment to be used by these aircraft.

There will be a continued need for ground based instrument landing systems. There is, however, a need to improve their accuracy, to take care of the increasing density of traffic.

In-flight navigational systems will need to be handled in the future by automatically programmed, more sophisticated navigation equipment.

Collision avoidance systems are required which will provide greater in-flight safety.

Investigation of possible navigation satellite systems is in progress. This investigation could culminate in a system which would be a unified communications, navigation and identification system (U-CNI). Such a system probably could not be implemented before the 1980-1985 period.

There is an increasing demand for access to the common carrier network for private telephone communication. This requirement is to give

the private citizen a method of normal type telephone communication between the private or commercial aircraft and his business or home.

Demands upon the ground communications network will increase due to the needs of auxiliary services at various locations connected with navigation or positioning of aircraft. This will also be true for administrative and control purposes, in the handling of reservations, passengers, baggage and freight, weather data, etc.

2.3.3 Land Mobile Communications

Background

The development of the land mobile service in Canada has essentially parallelled the development in the United States. There has been some lag in the adoption of certain types of service due to variation in needs and in regulatory conditions in the two countries. Law enforcement agencies were the first users. The initial systems operated in the HF band, first with one-way and later two-way communication. This took place in the years just prior to World War II. After World War II the possibilities for greater use of the land mobile services became apparent and wider usage occurred with the rapid development of equipment for use in the VHF section of the spectrum. This provided the possibility for many more frequency allocations.

As mentioned, law enforcement agencies were the initial users of land mobile equipment and systems. Systems are now used in taxi fleet operation, public utilities, construction, mining, lumber, etc. Private systems have been extended to man-carried equipment for paging and alerting purposes. There has also been extension of the common carrier communication network for operation in the land mobile and man-carried field.

According to Canadian Radio Technical Planning Board data the growth rate has been approximately 15% per year for licences in the land mobile service. They estimated that the number of mobile units in service at the end of 1968 was of the order of 100,000. They also estimated the land mobile business in Canada to be at a level of approximately $17 million for that year.

Anticipated Demand

Improved mobile communications derive from augmentation of, or extensions to, existing systems through use of new information systems and/or technology. It is not possible to be precise about the impact of the new information systems and techniques but needs can be foreseen and related to known technological possibilities.

Information items that have been identified as being important to the mobile field include:

- Record - form communications (hard copy)
- Vehicle location information
- Vehicle status monitoring

- Computer access from vehicles
- Mobile and portable alarm and signalling
- Mobile visual systems.

Each of these implies additional communication capacity and a corresponding increase in radio spectrum requirements. Each is of a generic nature and is thus applicable, in varying degrees, to all major categories of land mobile communications. It is not unrealistic to expect that they will all be implemented on a widespread basis in the next decade.

Added to these are the many unsolved mobile communications problems. Examples include radio aids for the distressed motorist, emergency monitoring and guidance information systems for medical purposes, air and water pollution monitoring and policing. As solutions to these requirements are found and implemented more spectrum will be needed. This growth must be planned for if the benefits of these services are to be realized.

The effect of more sophisticated and extensive mobile communications on future frequency spectrum needs will be very great indeed. The needs can easily be many times greater than those required by present day voice systems. As solutions are found to the evolving mobile communications requirements, a significant growth can be expected in the number of vehicles and persons equipped with radio communication devices. The rate of growth is expected to be several times greater than that existing today.

2.4 DATA STORAGE AND PROCESSING

Opposing Trends

The future of the data storage and processing problem is directly related to future division of computing effort among the various size categories of computers. In particular we are presently confronted by two opposing trends: one toward the mini-computer, in the limit a box on your desk or in your pocket; the other toward the super-giant, with enormous memory capacity, high computing speed, probably with many hundreds of satellite terminals scattered about the country. Certainly the communications needs of these two extremes are vastly different. It is therefore important to consider the advantages and disadvantages of each in order to prophesy the likely conditions that can be expected over the next two decades.

Advantages and Disadvantages of Size

There certainly are many advantages to a large central computer utility, but there are many disadvantages too. An assessment of the probable direction our data processing industry may take must consider both the good and bad features of all possible systems.

First of all it should be clearly understood that a large CPU (Central Processing Unit) and a large memory are not necessarily simultaneous requirements of a computing system. However, in general, there is likely to be a sizeable CPU requirement for processing the demands of a large number of terminal users operating simultaneously. This is necessary to optimize time and the use of hardware in the memory section which, in the case of data banks, is very large. Furthermore a large computer for carrying out intricate and long calculations must have both a large CPU and a large memory. Still there will be cases where the quantity of data stored may be very large and the number of terminals modest, so that a large CPU will be unnecessary in every case. Presumably the large memory and CPU requirements though married will be specified separately according to requirements.

Where would these large data-banks be needed? A few specific examples of desirable reference banks include: libraries, legal data, medical data. This class of information probably must be made readily available to many users from a central source, but because the user groups are quite different, it is not at all necessary for one single source to provide all information. Indeed each sub-category listed above would surely be large enough to warrant its own facility. But we must not fall into the trap of assuming that it is always better to do a job with a computer. Many of these reference services may be better handled by hard-copy libraries for many decades to come.

There is a definite psychological advantage to a user in having his own private system under his complete control. Other things being approximately equal this is the choice most businessmen would probably make. A decided advantage is the security consideration. Casual telephone conversations are by no means immune to interception: confidential information stored in a commercial computer is only as safe from disclosure as the cost and sophistication of encoding and decoding equipment in use at the terminal allows. This equipment may be too expensive—too costly for many commercial users. It must be noted here that the security of information whether in a computer or enroute is dependent on the lack of sufficient incentive to steal it and lack of knowledge of its probable value to the thief.

A reliability comparison of the two systems (central computer and local mini-computer) may give a slight edge to the mini-computer. Its MTBF (mean time between failures) will certainly be much longer, although the large computer installation can afford a permanent maintenance staff and will undoubtedly utilize advanced redundancy techniques. A failure in the communications link, however, will disrupt operations just as successfully as a downed computer. Furthermore a serious fault in the computer centre, e.g., a major power failure, could have serious repercussions on many users.

To centralize or not to centralize; that is the question. Centralization for its own sake is to be deprecated; centralization of *any* facility should be undertaken only if it is *advantageous* to do so. The bigger is not always the better. To quote Robert M. McClure, associate professor, Computer Science Center, Southern Methodist University: "As the makers of super tankers and super airplanes have discovered, 'superness'is not always an unmixed blessing".

In the final analysis it is economics that will influence the decisions. As an extreme example, one very large computer to serve the whole country would undoubtedly be an uneconomical approach, just as would a private computer for each individual. Any "excessive" centralization would probably not be in the national interest either, for several obvious reasons.

Conclusions and Comments

The next twenty years will see many changes in the field of data storage and processing. The number of computers will increase many-fold, with the greatest increase expected in the smaller systems. At the same time, however, the need for economical and reliable communication will also increase greatly for the medium to large-size computer complexes. It will be interesting to note the conclusions and recommendations of the Computer Study Committee under the chairmanship of Dr. Leon Katz set up recently by the Science Council of Canada. Most of the technological requirements are already within our grasp or on the horizon, but we can expect that many surprise developments will have their impact on the future of our computer systems.

3. BASIC TECHNOLOGY

GENERAL

In the following an attempt is made to look briefly at some of the technologies that are considered to be basic to the developing trends in communications. This particular study is "working from hardware" and it is appropriate to consider where science is leading in these fields.

It will be realized that only certain technologies can be covered and since each has many ramifications the coverage is necessarily general. Appendix B contains ten separate parts. This has been summarized on seven pages.

3.1 MEMORY TECHNOLOGY

Memory or storage of data is vital to digital computers, to communications technology and to all aspects of data handling and display. Memory will be incorporated into many communications systems on a large and increasing scale. Present steady trends towards lower prices, smaller size and increase in speed are considered unlikely to have any limiting effect upon the development of communications.

Important factors in choice of memory include the application, reliability, cost, speed, size, operating power, etc. At present ferrite core memories are maintaining overall superiority. It is expected that they will hold the dominant position until at least 1980 and that

competition will lead to improvements in them. Off-the-shelf ferrite memories in large scale arrays now cost about 1.5 to 8 cents a bit depending on speed, etc.

Semiconductor memories in integrated circuit form are being used increasingly, particularly in small computers. They are the most likely to develop quickly enough to overtake ferrite core memories before 1980. Their competitive position is tied to general development in integrated circuit technology. Present costs are about 1 to 50 cents a bit depending on type and characteristics. Projections of from 0.5 to 0.1 cent a bit have been made.

In the decade 1980 to 1990 memories with greatly improved storage densities will be needed. The recently announced magnetic bubble technique appears the most promising with holographic memory following. Bubble memory coded data files have been predicted that hold 15 million coded bits of information, occupy one or two cubic inches and use only 0.040 watts of power. Costs of 0.001 cent a bit have been mentioned.

If commercial bubble devices appear in the 1970-80 decade they could markedly affect the structure of computers, data processing equipment and the above prediction on the use of ferrite core memories in this period.

There is the distinct possibility that the input-output devices to the memory will determine overall speed of operation and control the incorporation of all types of memories into communications systems.

3.2 SEMICONDUCTOR TECHNOLOGY

The evolution of semiconductor technology and the industry has been revolutionary. The computer field has set the pace for most present developments. Communications will be affected by all aspects but probably particularly by the availability of digital circuits.

It takes three to five years from invention to significant marketing. It takes about 10 years for the device or process to reach maturity of bottoming of price and high reliability.

Semiconductor device technology will be predominately based on silicon in the twenty year period. The average price of silicon transistors is now just under 50¢. Dollar value of sales of silicon devices has been steady since 1966.

Integrated circuit sales are increasing linearly with time. Integrated circuits will continue to use silicon as a primary vehicle in the next two decades. They will reach maturity using present approaches by the late 70's and are expected to be under $1.00 a package. Integrated circuits will dominate the market in the 20 year period. Large improvements in complexity of function and reliability are expected with corresponding effects on size, capability and maintenance of communications systems.

The decade 1970-1980 should bring significant improvements in high frequency devices for microwave use and microwave integrated circuits, with maturity occurring in the mid 1980's. Some workers are predicting 250 kilowatt pulses at 100 GHz. At present, silicon transistors that give 5 watts in continuous operation at 3 GHz are available. New concepts in microwave systems, such as phased array antennae and millimetric transmission links are forcing the pace of microwave device and component research and development.

Inexpensive light emitting devices for use in displays and signal coupling will reach maturity in the 1970's. These are based on compound semiconductors.

The present semiconductor component market is in the vicinity of 1.5 billion dollars per year. As a result, every facet of the semiconductor band gap is being explored. There are many ideas being investigated that will give rise to new devices in the twenty-year period considered.

3.3 COMPUTER TECHNOLOGY

Continued growth of size and numbers of large computer installations is seen for 1970 to 1975. The use of small computers is increasing due to falling costs of memory and logic. Lower costs will allow more diverse uses of computers.

The number of instructions executed per second by large computer installations will increase 10 to 100 times per decade to 1990. This will be attained both by increased circuit speed and parallelling, etc. Specific gains seen include:

(a) fast (10^{-9} second) complex, low-power integrated circuit arrays,

(b) batch fabricated fast memories (cycle time to 10^{-9} seconds),

(c) microprogramming giving increased speed and flexibility,

(d) bulk random-access memories.

Extremely low-cost small computers will be mass produced. The use of interactive remote terminals will increase. Graphic or alphanumeric input-output devices will be common. Voice communication with computers and optical character readers will develop significantly.

Software (program writing) will be improved in cost and effectiveness by greater application of computers themselves to program writing. Communication with computers will be in more natural language. Large assemblages of computer resources will be deployed to produce software on demand.

Reliability will cease being a limitation on system size and complexity.

Costs of large computer installations will continue to increase 10% per doubling of capacity. Costs of small computers should decrease.

Effects

1. There will be large data banks throughout the country accessed by many people through simple terminals or computer installations.

2. Providing communications for data processing will do much towards forcing the use of digital transmission and electronic switching in communications systems. Because of the fast growth of data services the present estimated growth of channel capacity of 10 to 100 times per decade will continue. Continued automation will also be essential.

3. Computer technology will make possible:

(a) Automated communication switching centres,

(b) Controlled allocation of communications system resources,

(c) Dispersed switching centres for local traffic,

(d) Queued storage in memory units at strategic system points.

3.4 TRANSMISSION TECHNOLOGY

The available methods for transmitting signals from place to place can be divided into two broad classes, guided wave systems and propagated wave systems. The former have the advantage of being non-interfering and thus are not limited by the available radio frequency spectrum, they are, however, generally more expensive until quite large numbers of equivalent voice channels per route are required.

Guided wave systems include; paired cable capable of supporting about 100 voice circuits or one picture phone circuit per pair; coaxial cable systems capable of supporting 8,000 voice circuits, or 80 picture phone circuits, or 12 broadcast television channels per tube; waveguide systems with more than ten times the capacity of a single coaxial tube; and finally optical systems with a further tenfold or greater increase in capacity.

The larger capacity systems have a higher total cost but offer considerable economies in cost per channel where circuit density is high. Multitube coaxial cable systems will be economic in the mid 1970's on high density routes. If demand grows as expected waveguide technology should be economic in the 1980's on the heaviest routes and optical systems may become attractive towards 1990.

Propagated wave systems include; low capacity high frequency radio systems for fixed station use; mobile radio systems; broadcast radio and television; microwave radio systems with capacities of up to 1,800 voice channels per radio channel and ten or more radio channels per route; tropospheric scatter systems with capacities of a few hundred voice channels (repeater spacing is five to ten times that of microwave systems but this technique will not support television channels); and finally satellite relay systems with characteristics similar to microwave systems but employing earth orbiting satellite repeater stations.

Mobile radio needs can be served only by propagated wave systems without limiting the range of mobility. The limited radio spectrum available is therefore a very serious handicap. Reassignment of radio spectrum now dedicated to other services may be the only way to meet the rising demand for mobile communication services.

Improved versions of present day microwave radio systems should continue to provide an economic solution for moderate circuit density routes in many parts of the country. Digital microwave systems in the 10 to 20 Gigahertz region of the spectrum with capacities of up to 30,000 equivalent voice circuits are promising for application in the late 1970's and early 1980's.

A domestic satellite system is planned for operation in the early 1970's. Satellite repeater stations are quite expensive and this technique can only compete with terrestrial radio systems where distances are very great. It has special advantages however for television distribution where the same signal is used by many receiving stations and for the provision of television to remote northern communities. Digital techniques will also be applied to satellite circuits and will make possible the shared use of satellite circuit capacity on a demand assignment basis in the latter part of the 1970's.

3.5 POWER SOURCES

The cost of small turbine engines is expected to fall sharply during the 70's, and could lead to their widespread use as prime movers for small portable generator units.

A presently available silent source of continuous power is the thermo-electric generator, which is a long-lived low-voltage device capable of operating from low grade fuels. It is expected to continue to serve a well defined need for some time to come.

Steady but undramatic progress is expected in the development of fuel cells with the hydrocarbon/air system showing promise for the 70's. An off shoot of the fuel cell has been the metal-air cell which should be very attractive for use with small portable units.

Power requirements for satellites will increase twenty-fold over ISIS B by 1980, and will likely be met by solar cells and suitable energy storing devices. The introduction of proper charge control would permit more efficient use of the Ni-Cd system, while the H_2/O_2 fuel cell as a rechargeable battery, expected by the mid 70's, offers the possibility of greater energy and power densities. The cost and dangers of radio-active pollution still remains as problems with the radio-active isotope fuelled thermo-electric generator for space use.

For terrestrial use the greater capacity of manganese alkaline and reported long shelf life of magnesium primary cells will likely reduce the use of lead acid, Leclanche and zinc mercury systems.

The use of active chemicals in non-aqueous electrolytes, which deliver higher voltage and energy per cell, promises an increase of five to ten-fold in energy density. It is anticipated that prototypes will be available before 1980.

The possibility of self energized integrated circuit modules stems from the discovery of a new salt of rubidium, silver and iodine, and solid state batteries based on this electrolyte are being developed.

3.6 ANALOGUE AND DIGITAL FILTERING

It is expected that RLC passive networks will continue to be important for the next twenty years, but that their share of overall network production will drop considerably and that more significantly their limitations will probably not determine system design to the same degree as in the past.

Active filter applications will broaden as new low cost operational amplifiers with better gain bandwidth product are developed. Within several years, active filters will be competitive to 100 kHz and usable to a few MHz.

The monolithic filter is becoming common for narrow bandpass filtering in the range 3-30 MHz, and it is expected that in a few years monolithic technology will fill this type of requirement over the extended range 2-60 MHz. Crystal technology will improve mainly from better processing methods and controls.

Within five years all the required devices should be available for economical communication systems using digital filters. Arithmetic units with integrated 12-bit adders and 7-bit multipliers will be typical building blocks for such filters.

The availability of good microwave transistors will permit extensive use of active microstrip filters with gain.

The acoustic surface wave filter will permit economical transversal equalizers to approximately 100 MHz. New low-cost wideband operational amplifiers will also assist this trend since the tap points require buffering and summation.

3.7 INPUT-OUTPUT TECHNOLOGY

Input-Output devices extend from the acoustic transducers of the telephone handset to the video sensing and display devices of picturephone and television systems. They also include various data input and output units such as alphanumeric keyboard instruments and display units and various printing units which can produce hard copy. Character recognition devices already exist which generate data signals from printed characters and research is being directed towards speech recognition systems. Push-button dials can be used now to interrogate distant computers which use machine organized spoken words to reply.

Electret microphone units will begin to displace the carbon granule transmitter of the telephone handset in the early 1970's. They will provide much lower distortion and operate on much lower loop current.

Cathode ray tubes will predominate for visual displays during the 1970's but will begin to be displaced by solid state devices for data applications about 1980 and for color and half-tone images by the late 1980's. Solid state sensors will probably begin to compete with TV camera tubes towards the end of the 1970's. These solid state display and sensing devices will offer the advantages of small size, high reliability and low-voltage operation.

Deflected ink-jet and electrostatic carbon migration techniques can produce graphic as well as alphanumeric hard copy and are beginning to compete with impact printers. Strain-sensitive semiconductor devices hold promise of replacing mechanical contact structures for keyboard applications by the mid 1970's.

4. THE IMPACT OF TECHNOLOGY ON THE ELEMENTS OF COMMUNICATIONS SYSTEMS

GENERAL

Fundamentally, a communications system consists of a signal or message source, a means of transmission to a remote point and a means of reproducing the message at the receiving station.

In modern electrical communications the signal can be voice, frequency shift-keyed teletype, visual (as TV), hard copy (facsimile), digital data, etc. The transmission may be by wire link, by coaxial cable and by unguided or guided electromagnetic radiation. The final output may be intelligible voice, printed word or pictures,pictorial display, chains of pulses fed to a computer, etc.

The increasing need for economical, compatible and reliable communications of acceptable standards and capacities presents the technological challenges. These challenges are reflected in the organization of communications networks, in systems elements and in techniques generally.

In this section the impact of technology on the basic elements of communications systems is discussed. The emphasis is chiefly on the elements of the common carrier telecommunications network. Other services, such as mobile communications, broadcasting, satellite communications, data storage and processing, etc., that are wholly or partially outside of the common carrier network are discussed. However, most of the discussion is concerned with elements of what is by far the largest Canadian communication system.

The Switched Communications Network

The model used breaks the network into *transmission, switching* and *input-output (transducer)* equipment. This model, while useful, is not

precise. The elements, especially with newer techniques, tend to become inseparable. Also, all three elements are not always needed for a service.

A man or machine inputs energy, the transducer translates it into a form suitable for transmission and it passes over a local distribution loop to the local switching centre. The switching centre selects the desired connection. In an intra-office call the called subscriber is connected directly within the same local switching centre. In other (inter-office) calls, the connection is made through a succession of switching centres and transmission facilities to the remote local switching centre and local loop through which the called subscriber is connected by input-output equipment.

The whole presents a complex systems engineering problem and the continuing objective is to optimize the total network rather than each sub-system to reduce costs of information transfer and still allow new services to be provided economically. Besides such basic factors as channel amplitude-bandwidth, signal-to-noise, modulation efficiency, distortion, etc., and their interrelation, there are economic trade-offs on the standards that are practical. Signalling and supervision control and bind the network together and must be compatible with existing plant. There are also problems of office size, concentration, route selection, device lifetimes, total system reliability, sufficient redundancy and flexibility, etc., that must be related to forecast traffic patterns and future services.

New and improved devices and technology are the tools for meeting the objectives. Experience shows that discovery to development takes two to five years and system development to product takes up to five years for major sub-systems. Because of necessary trials, etc., this lag will not change much. It will continue to be necessary to freeze ideas to meet market needs before optimum technology is available.

4.1 TRANSMISSION

Transmission will be defined as the transferral of information between the sender and receiver of information, and all transmission systems can be usefully subdivided into three components; the transmitter, the transmission medium over which the information is transmitted, and the receiver. As an example, a modern transmission carrier system would be broken down as shown in Figure 6.

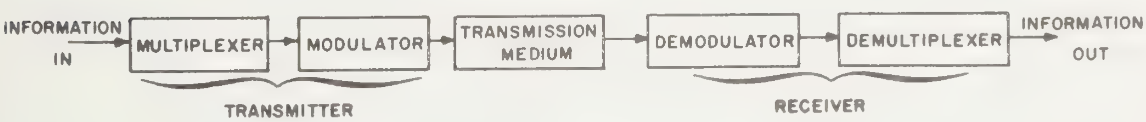

Fig. 6. Basic components of a carrier transmission system.

For any other example the three blocks may be more or less complex.

Three Types of Transmission Systems

In addition to the basic subdivision, since transmission systems exist in various points in the communication system and their characteristics are determined by different factors and economics, we will define three types of transmission systems as they exist today. The first is the exchange distribution facility or local loop which connects a users' transducer to a local switching centre.

The second is the short haul facility which interconnects local switching centres or a local switching centre to a tandem switcher. The third is the long haul facility which is used for long distance transmission between tandem switches.

Fig. 7. Illustration of the network transmission facilities.

Generally speaking at the present time, the exchange distribution facilities are less than 10 miles, short haul facilities will be less than 250 miles, and the long haul facilities will be anything longer than 250 miles. The lengths are purely dependent on the economics of the facility and the organization of the communication system, hence we should not consider this to be an inflexible model.

4.1.1 Modulation and Multiplexing

The actual physical transmission system can be either extremely simple such as a pair of wires travelling a few feet carrying analogue information, or it can be exceedingly complex where many channels are combined or multiplexed to travel several thousand miles over a microwave radio carrier. We can, however, define three types of multiplex schemes which will cover all of the major systems used today for multichannel transmission.

The first and oldest form of multiplex is space division (SD) where individual channels are spatially separated. Examples of this type would be parallel radio structures or for that matter a simple multipair cable is a crude example of space division.

The second form is called frequency division multiplex (FDM) and the carrier terminal or transmitter allows us to stack many channels separated in frequency. In order to combine or multiplex a number of voice, data or other channels into a single broadband spectrum for transmission over the medium, the information from each channel is used to modulate one of a number of multiple single-frequency carriers known as subcarriers. The modulated subcarriers are then summed to produce a wideband spectrum suitable for the transmission medium over which it

will be transmitted to the remote receiver. The modulation of the sub-carriers is achieved by continuous wave modulation where the carrier amplitude (amplitude modulation — AM) is usually varied in accordance to the channel information. As an example, a typical long haul FDM facility will derive its channel stacking using single sideband AM and then the complex waveform will be used to frequency modulate (FM) a microwave radio carrier for transmission through the atmosphere.

The third form of multiplexing although understood for many years is only now becoming a major economic reality. This is the time division multiplexing (TDM) scheme which allows the combining of many channels by simply separating the individual channel information in a sequence as a function of time. Provided each channel is sampled and transmitted at a rate exceeding twice its original occupied bandwidth, the total channel information can be transmitted along with the other channels on the high frequency transmission medium. Because of its discontinuous nature, the modulation scheme used must be a form of pulse modulation in which the pulse height or amplitude (PAM), the width or duration (PDM), the position (PPM), or the coding (PCM) is varied in accordance with the channel information. An example of this method of multiplexing is the short haul PCM carrier system introduced into the common carrier network in 1965. This system samples the information in each channel forming PAM samples which are interleaved in time and encoded into seven digit binary codes (PCM). The resulting groups of digits along with signalling information are then transmitted on a paired cable medium.

4.1.2 Evolution of Transmission Systems in Canada

Transmission systems have changed greatly over the past two decades in Canada. Systems which have made more efficient use of existing transmission media have evolved with the highest rate of change resulting from the introduction of solid state devices in the last decade.

Long Haul Facilities

Since the first transmission of telegraph in Canada until as late as 1940, the majority of transmission was via open-wire communication lines. Twisted wire pairs in multipair cables were introduced in the late 1930's in Canada and provided greater route densities, but the techniques used were variations of the same technology of loading and amplification. Associated problems with high circuit noise, crosstalk and delay on physical cable pairs probably set the stage for advances in technology which allowed the concept of "Shared Use" of a transmission media to be practicable for transmission facilities in the late 1940's. However as late as 1948, 100% of the coast-to-coast facilities and about 95% of the remaining long haul facilities were on paired cable and open wire. The first shared use or multiplex systems were primarily FDM-AM type carrier systems on paired and open wire facilities. As well as providing a gain in the cross-section capacity of 12 for existing cable plant, this system provided necessary improvement in transmission quality.

Microwave transmission systems which are basically line-of-sight radio systems were successfully introduced into the communication system in the mid 1950's. They provided a large number of channels with improved transmission quality and a reduction in absolute delay which had been known to be subjectively objectionable on coast-to-coast telephone calls. The system as well as affording greater fidelity for radio program facilities, also provided the first means of live long distance television video transmission. Microwave systems now provide our long haul coast-to-coast transmission operating at frequencies in the 2, 4, 6 and 7 GHz bands. Present technology and design procedures have achieved operational capacities of about 300 ch in the 2 GHz band,960 ch in the 4 GHz band, 1,200 ch in the 6 GHz band, and 1,200 ch in the 7 GHz band per radio channel.

Another radio system, the tropospheric scatter system operating in the 600 MHz to 4 GHz frequency band was developed and put into service in the late 1950's to provide communications to the Canadian north. With transmitter powers of up to 10 kilowatts and antenna gains of 44 dB, repeater points were required every 150 to 200 miles rather than the 25-30 mile spacing required for the conventional microwave systems. The system provides up to 250 voice circuits or equivalence in data, audio program, or slow scan TV video for future rebroadcast.

The latest addition to the long haul facility is the communication satellite. Used initially for intercontinental communication it will eventually be used for domestic communication in Canada. The satellites now operate in the earth-to-satellite link at 6 GHz and in the return path at 4 GHz. Basically it provides a facility in which the costs are not related to distance. However, at the present time terrestrial facilities are more economical for any circuit lengths encountered in Canada excepting certain far north applications.

Because of the absolute delay that the signal encounters in its 44,600 mile trip to and from the satellite (0.3 sec), special measures need to be taken if the circuit is to be used for two-way voice communications. Problems are also created due to the long turn-around time which the delay imposes on two-way high speed data circuits.

Short Haul Facilities

Again the short haul facilities were initially provided on open wire and paired cable using associated techniques. Carrier on paired cable was introduced in the early 1950's as reduction in FDM carrier terminal costs made carrier economically competitive at shorter distances. With the introduction of the first PCM-TDM carrier system in the mid 1960's, carrier became competitive with paired cable facilities for distances greater than 15 miles while at the same time improving the transmission quality and making better use of physical cable plant. Since 1965 large quantities of PCM carrier have been put in service by the common carriers and at the present time Canada is the second largest user of PCM in the world.

Exchange Distribution Facilities

As late as 1946 open wire, drop wire, and multipaired cable provided virtually all of the exchange distribution facilities. Today the situation is not significantly different although paired cable has replaced the majority of open wire. Voice frequency physical pairs are still more economical to provide than other forms of distribution plant. This situation will change however, as the cost of electronics decreases and higher information rates are required by customers. Additional forms of distribution do exist today to meet special customer needs. Coaxial cable, video cable and microwave are all used to provide distribution facilities for television program material for broadcasters. Special loading, equalization and amplification are provided on radio program, wired music and data distribution facilities. Separate one-way distribution systems have been created for CATV using coaxial cable distribution. Mobile radio and personal paging are provided over HF and VHF radio distribution. Fringe radio service operating in the VHF band provides single service distribution up to about 50 miles while high frequency radio service in the high frequency (HF) band is currently used for similar distribution up to about 2,000 miles in the far north. HF radio service does not have good service reliability and has high maintenance costs but is still the most economic means of providing this form of communication for the remote north.

4.1.3 Future Implications of Technology

Five principal factors will greatly influence all three types of transmission systems in the future common carrier network. These are system performance, cost, flexibility, capacity and maintainability and are all somewhat interrelated. The present system performance is not 'Utopia' but is based on state-of-the-art FDM techniques within the limits of imposed economic restraints. The ability of a system to provide flexible variable format in the grouping of various types of facilities for all types of information transmission, is exceedingly important in order to achieve the highest economies in trunking. In addition, the high rate of growth (12 to 17% per year) of the long haul facilities in Canada will make the use of much higher capacity systems with larger cross-section capacity, economic in the future. Finally, in the future, if for no other reason than to keep up with the growth, the maintainability of the systems must be far superior to todays systems. Practically if higher information rates are required in the distribution plant, electronics with much higher reliability, lower power consumption, and smaller size must become available.

4.1.4 Future Long Haul Facilities

Costs per channel mile have been steadily decreasing in Canada for long haul facilities as shown in the upper curve of Figure 8. The lower curve is the theoretical limit based on utilizing full system capacities as soon as they are introduced.

The decrease in costs of these systems has been brought about by the continual advances in technology in increasing the system cross-section capacities. The real economy is in the economy of scale of a

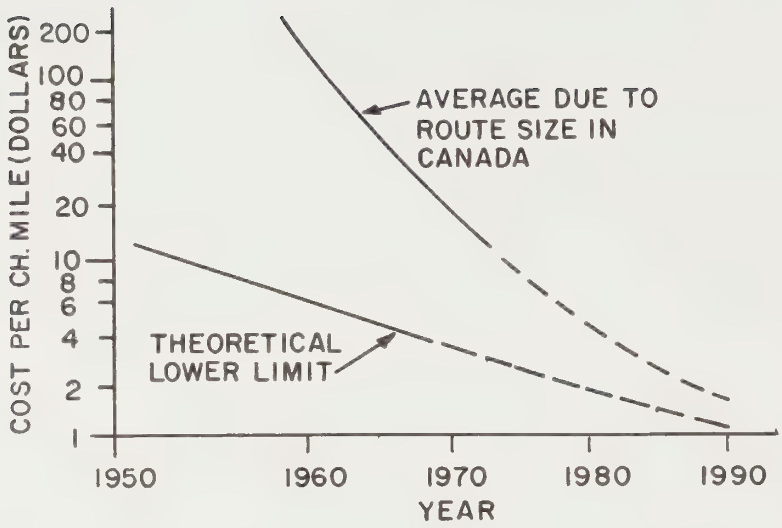

Fig. 8. Long haul facilities less terminal equipment.

route, and the upper curve indicates a trend to approach the lower limit, as the cross-section capacities increase in Canada. The curves shown are only approximate averages as actual figures vary significantly year by year especially when new routes must be introduce. It is significant that the costs of new technology have never been appreciably lower than the old during the first few years after introduction. The newer technology has the effect of stimulating innovations in the older technology.

For convenience, the future implications on the long haul facilities will be discussed in terms of terminal equipment (transmitter and receiver) and transmission medium.

4.1.5 Terminal Equipment

(a) FDM Carrier

The use of large scale integrated circuits (LSI) and digital filters in the analogue channel banks and multiplex stages is expected to allow for a substantial cost reduction in FDM type carrier equipment in the period 1975 to 1980. Moderate gains are expected prior to this period as medium scale integrated circuits are used to replace discreet component amplifier and multiplier stages. Beyond 1980 cost reductions in digital TDM systems are expected to far surpass any cost reductions in FDM carrier. Also due to maintainability and performance problems associated with analogue transmission, emphasis may be to reduce the quantity of FDM carrier systems after 1980.

(b) PCM-TDM Carrier

The introduction of second generation PCM-TDM carrier terminal equipment into Canada in the early 1970 to 1975 period for short haul facilities will provide moderate cost improvement with the possibility of greatly improved transmission quality in long haul facilities

starting in 1975. Associated coder decoder (Codex) equipment will also allow for superior transmission of audio and video program material with greater independence of system length and component degradation. Although it will be introduced in the mid 1970's full impact can not be expected before the early 1980's. Information of all types, voice, video, videophone, and data can be freely mixed with PCM-TDM without mutual interference problems which exist with FDM systems. It is also likely that some services such as videophone can only be transmitted economically in a PCM mode. Maintenance procedures are expected to be much simpler as self checking automatic maintenance can be built in at a minimum cost.

A third generation of PCM-TDM carrier and associated codex equipment will probably be realizable in the early 1980 to 1985 period. Here the modest cost and size reduction of the second generation equipment should be dwarfed. LSI's and the use of digital filters should reduce the size of PCM carrier terminal equipment by a factor of ten. Reliability may make circuit patching for restoration unnecessary reducing maintenance effort to a bare minimum.

4.1.6 Transmission Media

(a) Microwave

Two types of microwave systems will be discussed. The first will be FDM derived employing FM for transmission similar to the long haul systems in use today. The second will be a "digital radio" system carrying PCM-TDM derived circuits with regeneration of the information at each repeater point.

(i) FDM Microwave

The availability of reliable high power solid state devices suitable for operation in the microwave regions should provide complete solid state microwave systems suitable for top of the tower operation at reasonable cost by 1975-1980. During the same time frame cheap LSI's and digital filters should provide improved maintenance and cost reductions by providing cheaper analogue circuitry as well as some digital maintenance circuitry for built-in protection switching through redundancy. Inexpensive and reliable power supplies for remote locations will also reduce the necessity to man repeater points during the same period. Future capacity of these systems will be mainly limited by the available spectrum and the interference from other users. The frequency assignments today in the four bands allow for the following: The lower 2 GHz band — 3 working and 1 standby radio channel with 600 ch capacity per radio channel; the upper 2 GHz band — 5 working and 1 standby at 1,800 ch capacity per radio channel; the 4 GHz band — 14 working and 1 standby at 1,320 ch capacity per radio channel; the 6 GHz band — 5 working and 1 standby at 1,800 ch capacity per radio channel; and the 7 GHz band — 3 working and 1 standby at 1,800 ch capacity per radio channel. As mentioned previously these capacities have not been achieved today and with the frequency assignments in use, could only be possible on certain radio routes.

(ii) Digital Radio

To provide the necessary capacities and bandwidth for system cross-sections expected to be required in the future, we will be forced to use the higher frequency bands above 10 GHz. At this time, because of the large number of repeaters necessary to combat rain outages, it does not appear practicable to use FDM-FM systems at these higher frequencies. Digital Radio with total regeneration at each repeater point would appear to be much more attractive. In addition, although PCM on radio with four-level coding has only about 60% the efficiency of occupied bandwidth for voice circuits that FDM-FM systems exhibit, digital radio has an approximate 30 dB lower sensitivity to interference. This means that the same frequency can be reused more often resulting in better use of the spectrum in any geographical area. For other than voice circuits this system could be up to 10 times more efficient than FDM-FM without the better use of the spectrum being considered.

In the 11 to 18 GHz band digital repeaters housed in canisters and mounted on 60 to 100 foot metal poles would be required every 3.5 to 5 miles to form this facility. It is believed that capacities of the equivalent of 32,000 voice circuits per system can be achieved economically. This would date the system requirement for the late 1970's or early 1980's.

Although thermonuclear power packs are expected to be economical by 1978, propane generators available today make this system ideal for a transmission medium through the rocky territory of the north where trenching for coaxial cable or waveguide is an expensive proposition.

(b) Satellites

The first Canadian communication satellite 'Anik' is expected to be placed in geostationary orbit in 1972. It has been designed to extend the French language television network across Canada, to bring live television programming and telephone circuits to remote northern communities and to supplement existing terrestrial long-haul facilities in southern Canada by providing a telephone message and data link between Toronto and Vancouver.

Communication via satellite is a relatively new technology and it is not possible to fully evaluate the economics in comparison with terrestrial systems. Satellite communications also present unique problems due to solar eclipse, sun transit and significant path delays. However, operating organizations have not had difficulty in providing service during the highly predictable solar eclipse and sun transit conditions. The path delays of fifteen times the delay for cross-Canada transmission means that suitable echo suppressors are required in connections to two-wire lines. They must also be considered in data transmission if error detection and correction systems with feedback are used.

Future growth of satellite systems in Canada will depend heavily on the exploitation of advances in the supporting technology. Three

areas of activity hold promise of greatly increasing the potential usefulness of the satellite transmission technique. These are improved modulation techniques, advances in launch vehicle technology and the utilization of the frequency spectrum beyond 10 GHz.

Digital communication techniques have advanced rapidly in the past few years and may be applied extensively in commercial satellite communication systems in the 1970's. The digital techniques of pulse code modulation (PCM), phase shift keying (PSK) and time division multiple access (TDMA) will provide a distinct improvement in efficiency of utilization of the satellite transmission channel where a number of stations must share the same channel.

For example, a 10 station FM/FDMA system having a capacity of 450 one-way voice channels could provide 900 channels if PCM/PSK/TDMA were used. The example quoted illustrates an increase of two times in circuit capacity. However, even greater circuit capabilities may be achieved in the future if efficient trade-offs are made in digital systems between bandwidth, source encoding and signal-to-noise ratio. In the transmission of television signals it is expected that two television channels will be transmitted by a digital system with the same bandwidth and power now required to transmit one channel by conventional FM means.

Another improvement predicted for the 1970's is the introduction of digital echo cancelling devices. These devices are expected to eliminate adverse user reaction that may now exist on two-way voice channels due to inadequate echo suppression and the transmission delay associated with synchronous altitude satellites.

Fully variable assignment of satellite communications circuits between terminals in accordance with immediate demands for service, although not necessarily restricted to digital communications, can be most economically implemented by this means. The fully variable demand assignment system can permit a multiple access satellite system to service at least 40% more trunks than the instantaneous channel capacity of the system.

These digital communication techniques are in many cases already developed. However, it is expected that their commercial application to satellite systems in Canada will be on a small scale during the first half of the 1970's. The last half of the decade will no doubt see a full exploitation of their advantages.

Somewhat further in the future, it would appear that Canadian communication satellites will benefit greatly from the advances now predicted in launch vehicle technology. Increases in maximum achievable payload, (approximately doubling every two years), a continuing trend towards lower costs per pound in orbit (perhaps $500 per pound) and the availability of a space repair service would all contribute towards increased effectiveness of satellites as a transmission medium.

Existing restrictions on satellite design due to limited weight and life expectancy will give way to more complex systems in which the

processing of signals within the satellite will be feasible. This may lead to a capability to economically serve both small and large users scattered over a large geographic area.

In addition, satellites can be placed accurately in specified orbital positions and can be maintained there. This permits the use of narrow-beam antennas pointed to regions on the earth and will permit satellite-to-satellite relay to improve the utilization of the synchronous orbit and the use of the available frequency spectrum.

The third factor which is expected to have a significant impact on communication satellite systems is the development of the system concepts and the necessary hardware to utilize the frequency spectrum above 11.7 GHz which may require the use of spatially separated receiving antennas to overcome attenuation due to rainfall. The forthcoming World Administrative Radio Conference, to be held in 1971, will review allocations for the various services. Approximately 6 GHz of bandwidth between 11.7 GHz and 31 GHz may be allocated to communication and broadcast satellites. Confirmation of these allocations will hasten the necessary developments.

For Canada, the commercial application of these higher frequencies is not likely to occur before the late 1970's. However, the importance of these allocations in delaying synchronous orbit congestion and reducing costs of terrestrial communication links between earth station and population centres is assured.

Communication satellites also may be used to provide unique services in addition to trunk facilities and TV distribution. These include reliable communications to remote communities, isolated survey parties and ships and aircraft in northern Canada, data collection from a wide variety of sensors located over a large geographic area and navigation information to moving vehicles and aircraft. The provision of these services will depend upon the availability of suitable frequencies, the development of satellites with high radiated powers and the development of inexpensive ground terminals.

(c) Coaxial Cable Systems

A coaxial cable system offers a system which is in general, relatively free from interference from other co-channel sources. Satellites and microwave systems have an ultimate finite capacity based mainly on co-channel interference in any geographical area.

Cables are however, not without problems. Because of large temperature variations of transmission characteristics at the higher frequencies, it is desirable to provide a means of temperature control such as burying the cable. For practicable size cables, there is also an upper frequency limit of about one GHz above which frequency moding effects cause problems. The maximum voltage of about 11 kilovolts before breakdown for coaxial cables should be adequate for long route powering if effective means of circuit protection and filtering are used.

Two types of coaxial cable systems will probably have application in the next two decades — FDM cable facilities and PCM cable facilities.

(i) FDM Systems

FDM cable systems although not an optimum, may provide economical facilities during the 1970 to 1975 period. Problems still exist in long haul analogue video transmission on cable with respect to noise and delay distortion, and due to the intrinsic nature of the problem, no startling economic solution is predicted during the next decade.

Combination FDM-TDM Systems are possible and could have an impact in the 1975 - 1980 period. With such a system a 22 tube .375 inch coaxial cable system could provide for up to 90,000 voice circuits or the equivalent in other services.

Each tube would use approximately 65 MHz of bandwidth and provide either 9,000 voice channels of equivalent FDM derived or 195 M bits/sec of digital information. The repeaters for such a system would be required every mile and would not provide regeneration for the digital information at each repeater point. Regeneration would be provided at the end of the system for the digital mode of operation.

At the present time, transmission of Network TV video program material, or videophone on the long haul facilities is not economic on coaxial cable systems in other than digital form.

(ii) TDM Systems

The only use of TDM to date has been a PCM system. Because of the better co-channel interference capability of PCM systems, much better utilization was made of existing cable plant than could be achieved with FDM systems.

Future systems in the 1975-1980 time frame will be capable of providing TDM-PCM transmission media with bit rates of 280 M bits/sec. Repeater spacings of about 1.4 miles are possible. Each coaxial tube of the system would have the capability of three video channels, 42 videophone, or 4,032 voice/data circuits. Flexible combinations of all types can easily be provided. The total system could be any number of coaxial tubes, however, it would appear that a multitube coaxial cable of about 12 to 14 tubes is about the optimum size for manufacturing, plowing and splicing using present techniques.

The second generation system probably practicable by the 1980 to 1985 period should be capable of attaining at least twice the bit rate.

Although higher speed coaxial systems will no doubt be possible in the 1985 to 1990 time frame, the requirement for very large cross sections will probably dictate the use of even higher capacity systems with their associated economies.

One dark horse however, might be the possibility of a digital integrated coaxial cable where digital amplifiers on repeaters are formed in the centre conductor during cable construction. One major obstacle for such a system would be protection against surges on the line.

(d) Waveguide Systems

With projected growth rates, one very real possibility for initial cross-sections greater than 30,000 equivalent voice circuits will be waveguide systems operating in the 35 to 100 GHz band. Most of the technology for millimeter circular waveguide systems is available today. Waveguide is however, still relatively expensive and difficult to manufacture and place in the ground. The guide system, believed to be the most suitable, is the circular pipe helically wound inside with enamelled copper wire. This construction suppresses unwanted modes allowing the low loss TE01 mode to be transmitted. Present technology could provide systems with about a 280 M bit/sec capacity limited by the modulating equipment. A 30,720 M bit/sec channel supporting 480,000 voice circuits, 320 TV, 4,880 picturephone, or any combination of data, voice, TV and picturephone up to the channel capacity is possible per guide by the late 1980's. Future systems could also be with PCM derived groups of channels which are then stacked on an FDM basis on the broad spectrum guide. This is very flexible for growth as once established on lower capacity systems, it can be expanded by adding additional groups for higher capacity as hardware becomes available.

Because of the low loss of the waveguide (3 dB per mile), repeater spacings of fifteen miles will be practicable.

The required cross-section growth necessary to prove in waveguide systems is not expected in Canada until the 1985 to 1990 period. By this time advances in waveguide technology and repeater design and placement techniques may possibly make the system economic for smaller cross-sections that 20,000 voice circuit capacity. If true, waveguide systems will be a major contender for part of the coaxial cable market. For very high capacity routes however, another system, the laser optical system, may prove to be more economical.

(e) Laser Optic System

The principles of the laser were first discussed in 1951 by Townes and not perfected operationally until 1960 when Maiman constructed the first ruby laser. Much has occurred in the ensuing decade. Lasers have been modulated with PCM at 225 M bits/sec and much higher frequency modulators appear to be practicable in the 1970 to 1975 period and beyond.

The actual true transmission medium is one of the major obstacles, however, in achieving a laser optics communication system. Transmission through the unconfined atmosphere is not practicable because of the inability of light to penetrate fog, rain and snow. This does not however, preclude its use for satellite to satellite type of communication. For terrestrial use one possible means is to confine the modulated laser beam in a hollow pipeline with laminar flow gas lenses used to control the

beam divergence. Bends however are difficult to deal with. Practical bit rates for such a line should approach 10^{12} bits/sec before it would be required in the 1985-1990 time frame. One of the other major contenders for the transmission medium is the fiber optic path. Multilayer glass fibers which are extremely small in diameter and can be bundled together to form multipath cables have been demonstrated to be capable of carrying 10^9 bits/sec with a loss of only 20 dB per kilometer. This is a vast improvement from one year ago when losses were as high as 100 dB per kilometer. The fiber optic path will probably offer the better of the two solutions by 1985 as it is flexible, can be plowed into the ground and does not need to be straight as light follows the glass fibers without additional loss from bends.

Expected advances in transmitters, repeaters, and receivers could make this system economically viable for large cross-sections in Canada by the 1985-1990 period.

4.1.7 Future Short Haul Facilities

Because of rising labour, material, and right of way costs, the emphasis in the last decade was to obtain an optimum capacity — cost relationship from existing short haul cable plant through the introduction of electronics. This trend will continue in the 1970 to 1980 period and perhaps be accelerated during the 1980 to 1990 time frame. The effect of LSI's, digital filters and indirectly large cheap memory devices will have much more effect on the cost of short haul facilities than on the long haul facilities.

For purposes of analysis we will again subdivide the short haul facilities into terminal equipment (transmitter and receiver) and transmission medium.

4.1.8 Short Haul Terminal Equipment

(a) FDM Carrier

Various types of 12 and 24 channel FDM-AM carriers are in operation today on the short haul paired cable routes. In addition, 600 channel FDM-AM carrier multiplex equipment is used to form a multiplex hierarcy suitable for transmission on 2 and 7 GHz FM radio systems. Digital filters, integrated circuits, and inexpensive LSI's will give this FDM carrier equipment a renewed economic boost in the 1970's and early 1980's as far as terminal equipment costs and some built in maintenance features. However, the fact remains that analogue systems to date have been much more costly to maintain than the present PCM-TDM systems. In addition, terminal costs for PCM systems with their built-in signalling will prove more economic in the 1970 - 1975 period for small capacity paired cable systems and in the 1980 - 1985 period will probably prove more economic for the larger capacity short haul routes.

(b) TDM Carrier

PCM-TDM carrier has been in operation since 1965 in Canada and its use has been growing at a rapid pace. Audio visual services such as

videophone may provide the major restriction for FDM carrier systems as it does not seem economically feasible to trunk videophone in analogue form with foreseeable technology.

Second generation PCM carrier terminal equipment using IC's and discreet components will be available in the early 1970 to 1975 period. It will provide circuits with improved transmission performance over existing wire facilities and at a lower cost for circuits longer than eight to twelve miles depending on the type.

A third generation PCM terminal will probably be feasible in the early 1980 to 1985 period utilizing LSI's and digital filters and reducing the size of the terminal equipment by a factor of ten times. The introduction of PCM time division or space division switching made possible by LSI's and cheap memory technology, will also have an effect on PCM carrier as more PCM will be used on tandem routes with fewer terminal banks. Here the switcher will switch the bit stream without the necessity of demodulation, hence PCM carrier will be favoured most for growth in the early 1980 period.

Maintainability of the first generation PCM-TDM carrier equipment has been excellent. Future improvements in reliability and the introduction of large scale integrated circuits along with inexpensive self-checking capability of PCM carrier systems, will favour PCM carrier as a means of growth.

Means of higher order multiplexing from the basic 1.54 M bit/sec bit stream of the basic channel bank up to speeds of approximately 280 M bits/sec can be available by the mid 1970's for heavier route transmission over microwave radio or coaxial cable using multilevel coding.

4.1.9 Short Haul Transmission Media

(a) Microwave

(i) FDM-FM systems will find use in varying forms of sophistication through the 1970 to 1975 period. Higher power microwave solid state devices will allow for a fully solid state microwave system with decreased cost and improved maintainability for the 2 and 7 GHz frequency bands during the 1975 to 1980 time frame. Beyond 1980 even with careful management of available frequency spectrum, it may be desirable to retain frequency assignments for long haul facilities rather than for short haul routes.

(ii) TDM-PCM systems in the form of digital radio would appear to be far more economical in terms of geographical frequency spectrum conservation and expected improved maintenance. It is expected that this type of facility would be most attractive in the early 1980's for heavy short haul routes. The improved flexibility achieved from the digital facility will allow all types of information to be handled in an economic manner.

(b) Coaxial Cable System

Both FDM and TDM cable systems are possible for short haul routes. Current technology appears to favour digital techniques, hence TDM systems will be the most likely for future systems on a requirement basis. No new techniques will be required as they will be lower capacity versions of the long haul systems which could probably use the same digital repeaters. Cost studies do indicate however, that until at least 1985, multiples of paired cable PCM carrier are more economical than a medium capacity coaxial cable system where TV is not a requirement.

(c) Paired Cable Systems

Repeaters for these systems are presently utilizing the full cross-talk limitation of conventional paired cable of 1.54 M bits/sec. Further development will be in producing much cheaper, smaller more reliable repeaters using integrated circuit techniques. Ways of handling large surge voltage transients will need to be found before all of these three goals can be realized. It should be possible however, by the late 1970's or early 1980's to obtain an improvement of up to five times in all three areas. Size reduction, cost reduction and reliability of repeaters.

Use of a lower capacitance paired cable than is in use in present day cable plant, is the most likely system for the future short haul trunking in the metropolitan areas during the 1975 to 1980 period. Tests have indicated that repeater spacings of 2.5 miles can be achieved for a 6.3 M bit/sec PCM line capable of transmitting 96 voice, one picture-phone or the equivalent in other forms of information. Conventional cable would require repeater spacing of about one mile.

Development of a highly balanced single extrusion webbed paired cable may prove to be more economical for the longer short haul routes. A system employing this type of cable might enable the use of repeaters every ten miles on a 6.3 M bit/sec facility.

4.1.10 Future Exchange Distribution Facilities

Technology has been used effectively in reducing the cost of the long and short haul facilities and we have every indication that this cost trend will continue while transmission and flexibility also improve. When we examine the exchange distribution facilities and note a seemingly small improvement, it appears paradoxical that we have not been able to apply more technology to this avenue of transmission. At the same time we must remember that in todays technological climate it is not "can it be done", for anything is possible, but "can it be done more economically".

Our society lives in a spatially divided community. In order to distribute information where we do not have the economies of common usage, high capacity, long and short haul facilities, an economic length and type of facility must be used. In the next two decades, three basic types of facilities may find use in varying degrees. These are paired cable, coaxial cable and radio distribution.

(a) Paired Cable Distribution

Three basic categories in paired cable technology offer solutions.

(i) Regular twisted paired cable as found in the distribution today is inexpensive and offers the potential of a much higher information rate than it is used for today. Each pair has the potential of one-way transmission at about 1.5 M bits/sec with repeaters over 1.15 miles. Subscriber carrier employing IC's and digital filters could prove economical during 1975 to 1980 in providing a second line capability with much improved transmission quality. The concept of a new communications set by 1975 to 1980 employing tone alerting tone supervision, and reduced loop current or even remote powering could drastically reduce the gauge of cable pairs and hence, the cost of the exchange facilities.

(ii) Low capacitance paired cable similar to that used in short haul transmission facilities could also be introduced to allow for higher information rate type of services. With presently attainable values, a 6.3 M bit/sec facility is possible with digital repeaters every 2.5 miles.

(iii) Forms of highly balanced paired cable are also possible which would yield much higher bit rates or increased repeater spacings if higher bit rates are required. The common carriers have had many years experience with highly balanced cables.

In the past the costs of switching have been high in comparison with trunking. Today local switching costs are comparable with distribution costs. As switching units become smaller and less expensive in the 1980 to 1985 period it should be possible to decentralize the switching matrices. This may favour paired cable distribution as the subscriber distribution would become much shorter from the decentralized switches and their associated shared higher usage trunking. The shorter length of paired cable should mean no individual repeaters per subscriber loop for wideband facilities and would avoid the problems of longitudinal currents which are present on coaxial cable.

(b) Coaxial Cable Systems

Two basic layouts for coaxial cable distribution systems are possible, the coaxial loop and the dedicated switched coaxial system.

(i) The coaxial loop distribution system could be achieved on either an FDM or TDM basis. A broadband large coaxial tube would loop round a community connecting approximately 200 subscribers before returning to the originating point. Total one-way services such as CATV, FM and AM radio as well as two-way videophone, data and voice could be provided on the same facility. Present cost studies in progress may indicate that such a system is probably only economical for combined total services. Also in sparsely populated areas the system would not be as attractive as in metropolitan areas.

(ii) The second possible coaxial system is the individual switched coaxial distribution. Coaxial cable in a miniature form would be used in place of paired cable in the distribution network. Unlike paired cable the coaxial cable is not as flexible for splicing and rerouting after placement. With decentralized switching and depending on the degree of decentralized switching which is attainable, this system may have application if distribution of all types of information — videophone, voice, CATV, FM, etc. are provided.

Either system will require cheap reliable electronics both for station and repeater use. Although improvements in cost and size will be made during the 1970 to 1980 period, the major improvements will be possible with LSI and digital filters in the 1980 to 1985 period. Some special services such as the Network TV video program material carried for the TV Networks will probably be in digital form on some routes by the 1975 to 1980 time frame. As the number of routes increase the broadcaster will be required to switch in a digital mode to achieve the maximum benefits from the digital facilities. Local distribution will probably be on separate coaxial cable because of the extremely high bits rates involved.

(c) Radio Distribution Systems

Mobile radio, paging systems, high frequency and fringe radio, will be treated in this section.

(i) Mobile radio for the public use bears a close resemblance to the telephone in its early days. Future possible improvements are the elimination of operator involvement by adding dialing capabilities to the mobile stations when economic equipment is available to prevent fraudulent use. Before improved traffic capabilities can be realized a greater number of channels must be made available perhaps in the upper UHF band. Inexpensive solid state devices must also be available to allow use of several thousand channels in this frequency band where each set would have access to perhaps 50 channels on an automatic scan hunting basis. Frequency assignments could be made to give the user at least 20 channel access in any geographical location. Vocoder principles could be used perhaps by 1980-1985 to allow narrower channelling. Although a good deal of the necessary technology exists today, this type of service will only be economic with respect to other forms of communication if major cost breakthroughs can be achieved in the set costs and reliability. The complete installation costs at present are approximately $1,500 for this form of distribution as opposed to about $300 for conventional cable pairs.

(ii) A radio paging system is basically the alerting portion of a future portable communication system. Because of limited frequency assignments, operation in the VHF band would appear to make the addition of system wide roaming capability desirable for alerting but not for one-way voice. A more suitable approach will be to allow "answer and reconnect" capability in the calling network so

that the paged subscriber could dial his number from any telephone and the network would route him automatically to the original caller. This system would provide a much better use of the time frequency resources. Another alternative would be to forward the calling number to the called set in digital form for storage. These are all signalling functions and could be provided before 1975.

If frequencies are made available in the 100 to 200 GHz band, area wide two-way voice communications might be possible by 1990 using LSI's digital filters and high frequency solid state devices. This would provide a form of personal portable telephone service with the distribution portion of the network via radio. The set costs would again be the controlling cost for such a distribution system.

(iii) High Frequency Radio and Fringe Radio Service operating in the HF, VHF, and UHF radio bands will still provide the most economical type of service to the remote single stations in Canada during the next two decades. Cost reductions in terminal equipment will result during the same period as more IC's are employed in the sets. Similarily better modulation systems and error correcting codes can be used to improve the channels for data handling capability.

4.2 SWITCHING

In telecommunications, switching is used to select a called station and achieve a flexible network connection which makes the best possible use of transmission facilities. Without the use of flexible centralized switching systems, each customer would be required to do his own switching on his own premises and dedicated facilities would be required to interconnect each customer in the network. For n customers this solution would require the maximum number of separate lines equal to $n(n-1)/2$ (about 13×10^{12} in Canada) which is obviously unacceptable. At the other extreme, one single central switcher could reduce the number of separate lines to its minimum of n, (about 5×10^{6} in Canada) however, the average lengths would be many hundreds of miles long.

An economic network solution exists between the two extremes based on the density of the population, separation of major centres, the traffic or usage of the network, the total number of users, the cost of switching, the cost of transmission and the cost of property. The basic economy however, stems from the possibility of time sharing transmission paths to distant locations through the use of multi-switching systems.

Space Division Switching

The network configuration which has evolved in Canada is that in which a group of customers share a local switching centre which is linked to all other switching centres and, in the case of telephony, in a hierarchy type of structure which at present involves five levels of switching. This form of switching is performed with space division switching. With space division switching, crosspoints in the switch matrix establish a physical connection between customers for the total duration of the

established call. This type of switching can also be used to switch higher order blocks or groups of channels in the transmission multiplex. This is known as group switching.

Time Division Switching

An uninterrupted connection is not essential for the unimpaired transmission of information. Indeed this fact is utilized now in all time division multiplex carriers such as the PCM carrier used in Canada since 1965. In a time division switching system, or more properly Time Division Multiplex Switching System, each customer is assigned a singular time slot at which time his gate is opened or a connection is made between two points in the established call. Providing that the time interval between successive gatings is of sufficiently short duration undistorted continuous transmission is possible.

Call Store and Forward Switching

One additional form of switching is store and forward switching which can be accomplished by either space or time division switching but with the characteristic of delay introduced. Here the information is generally in the form of a message which is forwarded from the originator to the call store and forward switch, which stores the message until transmission can be performed to a user at a later time. Although many examples of store and forward have been performed in the past ranging from Telephone Answering Services to modern day digital computers which store, translate and route information such as Message Switched Data Service, the surface has barely been scratched for the potential of this form of switching. This one concept in itself provides an avenue for the higher utilization of the communications highway.

4.2.1 Evolution of Switching in Canada

Manual System

The evolution of communication switching in Canada to date can be traced back possibly to the early days of the telephone where with an adequate supply of wire and only few subscribers, connections were made physically as required. Improvements appeared as jacks were substituted for terminals and jumpers were replaced by patch cords. This form still exists on manual PBX switchboards where subscribers and trunks or subscribers are interconnected by an operator.

Progressive Switching Systems

The first attempt to avoid the use of a human operator in the switching system took place in Canada in the early 1900's when Strowger switches combined with a signalling device — the rotary dial in the home, allowed the switching function of selection and connection to be accomplished by the caller on a progressive step by step or digit by digit basis. This equipment quickly proved an economical way to avoid some of the disadvantages of the manual switchboard for large exchanges. However, it contained no memory as each digit caused an irrevocable path to be set up and if at any step in setting up the call a busy condition was found, the system was incapable of alternate routing and the caller was

forced to redial until a free path was found. Although this system was improved over the years to provide more reliability and access to a greater number of paths, the basic problem still remained.

Common Control Systems

In the early 1950's when the Canadian Telephone Companies were contemplating Customer Direct Distance Dialling it became apparent that the technique of alternate routing was essential to the long distance network in order to achieve flexible economic trunking between various cities. At this time, the first crossbar switching system utilizing common control equipment, memory capability and automatic trouble identification was introduced in Canada. Here the equipment actually used to establish the path was used only during the call setup and then was released to be reused on a time shared basis by other customers. Other new service features could be provided such as digitone dialling, special routing and a more economic method of accounting and billing through automatic number identification of the calling party. These more flexible systems were introduced slowly at first and as operating experience increased, they were introduced at a faster rate until at present they constitute approximately 40% of the total switching capability in Canada.

A side benefit which had been designed into these crossbar switches was a much improved performance with respect to noise and cross talk. Because of this latter feature the switch could also be employed for services which had previously been handled on a patched basis — Video and Audio program material. These services were thus established on a flexible crossbar switch which allowed large live network reconfigurations without impairment to programming.

As data services increased in the late 1960's the requirement for switched service became apparent. Services such as data broadcasting to several points on the network at one time, automatic network setups between individual stations, rapid setup, data speed conversion and data store and forward required switching capabilities not originally built into telephone voice switching machines. Again the crossbar switching machine common control flexibility proved suitable to provide the space division switching portion of the requirement. Local exchange crossbar type switchers serving existing voice traffic could and were thus used for this portion providing a solution with many of the economies of the full scale telephone switched network. Requirements for wideband data were handled again by existing local crossbar offices by the addition of four wire separated line and trunk switch matrices controlled by the existing common control equipment. Economies of scale were again realized for the data user as no new common control equipment was required.

Electronic Stored Program Control Switchers

Although these crossbar common control offices are still being installed, a new generation of switching machine was introduced into Canada in 1967 in the form of the electronic switching system utilizing an electronic stored program (ESP) common control. The first generation of these electronic stored program machines could not be the immediate answer to low cost switching with their discrete component central

processors, electromechanical crosspoints, and inconvenient memories. They did however, provide the badly needed design, manufacturing and operating experience on which the future generation of economic switchers could be built.

Experience with the electronic stored program control offices to date had indicated the extreme flexibility of this type of operation. New service features can be added to the program for all offices quickly with minimum expense. Features such as abbreviated calling, the ability to transfer calls, the ability to transfer or direct incoming calls to another location, and three way call conferencing are all examples of the type of flexibility that is available at minimum expense.

Call Store and Forward and code conversion of different data speeds and formats for user compatibility are more economically provided in a stored program common control switcher. Since these switchers were only first introduced into Canada in 1967 and in true commercial use in 1969 a small computer type of Call Store and Forward was introduced in 1968 to provide these services prior to combining the features in a future generation electronic stored program control switcher.

Similarly full duplex voice band data could be provided on existing stored program electronic systems, however since the next vintage of electronic switchers will provide a more economic integrated service by 1975, the interim existing traffic will be served on small crossbar common control switchers in Canada. However, by the mid 1970's it is clear that electronic stored program (ESP) switching systems will easily handle the complex setup patterns required for local and toll voice, data, radio program, and video program switching.

The high speed of the central processors for these future switchers will achieve the highest economy from high traffic usage and the integration of all types of services. Only through this approach will the user benefit.

4.2.2 The Future of Switching Systems

Three main areas of switcher technology presently require additional cost improvements.

Logic

First of all the cost of logic elements must fall drastically. In present day ESP switchers little if any use of integrated circuits has been made. Even so costs are only slightly higher than that of an equivalent crossbar system. When we consider the possible impact of large scale integrated circuits (LSI) where twenty or thirty flip-flops can be produced in a single device for the same cost as a present day single flip-flop, the future of ESP switchers will look increasingly more attractive in the 1975 to 1980 period. The use of smaller scale IC's during the early 1970's will also provide some cost reductions.

Memory

The second barrier is that of obtaining a cheaper, smaller, higher speed memory element. Even new ESP systems under field trial today and expected to go into service in Canada in 1972 are capacity limited by memory speed.

Fortunately at least three possibilities are on the horizon and one may meet this need. Metal Oxide Silicon Field Effect Transistor Memories (MOS), Ortho ferrite "Bubble Memories" and perhaps some form of Holographic memory technique will when developed for commercial use provide, as forecast, a cheaper memory with adequate speed. This will provide ESP switchers with inexpensive store and forward capability, making more economic use of the central processor. The time frame for availability of these devices is somewhat uncertain, however we should expect appearance of fast inexpensive bulk memories in switching systems in the period 1975 to 1980 which is coincident with the expected introduction of LSI's.

Although processor speed would be the next limitation today, processor speeds ten times faster than the switcher under field trial are expected to be available in the immediate future. Hence the barrier of memory speed is of paramount importance to cheaper switchers which will meet the increasing demands for fuller integrated communications.

Software Technology

The third obstruction to inexpensive ESP switching systems is that of Programming Techniques which includes both the case of programming an ESP office and the efficiency of the program in terms of machine or real time processing. Economics involving tradeoffs of programming time versus additional hardware must be explored to achieve the optimum solution. The use of more efficient compilers will be necessary in the future to obtain inexpensive programming and efficient real time processing.

Future Switchers

In general two classes of ESP offices will emerge depending purely on economies of devices.

Space Division Switcher

The first type will perhaps be an extension of the space division ESP office we know today. The glass encapsulated reed relays used in the first generation machines are expensive and at best only an interim solution to the switching matrix. The next version of switcher, which might be considered the next half generation, will for purely economic reasons employ a miniature version of the mechanical crossbar switch with medium scale integrated circuitry used in the central processor. Cost reductions have made possible a read-write type of memory in place of the read-only memory used at present. This will greatly simplify the updating of the program for customer change information.

For the true next generation space division ESP office, a technological breakthrough is required in the form of solid state crosspoints for the switching matrix. Three problems presently preclude the use of such devices today. They must handle a loop current associated with customer supervision, they must be capable of withstanding the high ringing voltage used today for alerting a called subscriber, and they must tolerate transients spikes from lightning and foreign attachments. Although a new station set could remove the first two problems, the protection problem would still exist. However, if an economic solution to the device can be found, a space division second generation ESP switcher is a possibility for the early 1980 period.

Time Division Switcher

The second class of ESP office at present holds an economic edge over the first for tandem type switchers. This is the true time division ESP switcher. Except for the transmission functions, all previous switching systems have from the very inception of automatic telephony used digital switching and logic circuits, as in the case of data processing systems today. With time division switching the similarity becomes complete and the switcher, cannot be discerned from the transmission multiplex equipment.

Tandem Switchers

Factors favouring the time division ESP switcher apart from not requiring more sophisticated solid state switches than are available today, are the economies which can be gained in tandem switching where large concentrations of PCM carrier short haul facilities are in existence today. Since cost studies have proven in, and current planning calls for PCM for long haul facilities, by the time a second generation ESP switcher is available, considerable saving can be realized by switching PCM directly rather than decoding prior to the switch. The use of PCM time division ESP switching would also remove to a large extent the necessity for a strict hierarchy of switching. A connection could then in fact, be made of many or few tandem points without introducing the transmission impairments on a cumulative basis that appear with space division analogue switching. With this form of integrated switching and PCM carrier, only one conversion from analogue to digital is made, if required, regardless of distance, and since the transmission quality apart from absolute delay is more or less independent of circuit length the quality of any two connections whether short or long, is identical. This would also apply on international circuits providing international compatibility could be realized.

The avoidance of modulation and demodulation at each switcher is the major benefit of PCM switching.

End Offices (Local Switching Centres)

The case for end or local exchange offices varies from that of the tandem offices mentioned previously. The end office is used to switch locally and provide a concentration point between subscribers and outgoing short haul transmission facilities. Because of traffic usage, fewer trunks are required than subscriber distribution facilities.

Hybrid Switching System

Since the encoder from analogue to PCM is at present an expensive part of the network it is felt at the present time that for telephone or any analogue type signals, the best place for the encoder is at the trunk location. This would suggest that the first level of concentration for analogue services be done with analogue space or time division ESP switching. The solid state crosspoint may or may not be required for this application. However, the capability of both time and space division switching can be built into the central processor and both types of networks can be available for use at one or many locations controlled by a central processor.

The controlling factors when increased bandwidths or digital facilities are required for the local distribution, are the cost of the physical high frequency line and the cost of the electronic equipment necessary to condition the line. Economies cannot be achieved in shared use of repeater equipment in the distribution facilities as for the case of trunking. If the customer could use the full potential continuously of say one PCM carrier system (1.5 M bits which is currently felt to be the economic limit of regular paired cable), then of course the economy is realized. Similarly other forms of local distribution have economic capacity length relationships, but in the majority of cases customers do not require bit rates approaching this order of magnitude. If required, however, these facilities could easily be switched on a time division matrix, controlled by the same ESP switcher and utilize the same trunking with format instructions given to the terminating office via a common signal control data channel.

Decentralized Switching

Future possibilities for local switching of all types of information beyond 1980 will probably include the decentralized switching system concept. Here the switching not only merges with the trunking as for the first generation of time division ESP switchers, but becomes an indiscernible part of the exchange facilities. The degree and rate of integration will depend primarily on three technological factors. First the speed available for central processors, second the cost and most important the reliability of LSI's, and third the size and cost of memory.

With this form of switching a large central processor capable of processing communication requirements for many tens of thousands of communication channels will be connected via common signal channels with its adjacent mates. Time Division or Space Division switch matrices will not be centrally located but will be evenly spread throughout the exchange plant. Nodes of switches will in turn be connected and controlled remotely from their central processor allowing economies of concentration closer to subscribers and at the same time shorter subscriber facilities. As the local facilities become shorter the feasibility of non repeatered wideband digital or analogue format for local loops becomes more of an economic reality. Transmission from the switch nodes back to the first tandem switcher would of course be via digital facilities, hence all types of customer communication needs would be available on shared facilities from switched node to switched node.

4.3 TRANSDUCERS

For our purposes transducers are defined as the elements of a communications system needed to convert human or machine action or information into related energy which can be transmitted by electrical means. The complementary action of reconverting the electrical energy more or less faithfully to provide information output, is implicit in the definition. A transducer is a real time device, although the relevant data may be operated upon in many ways before, during and after transmission.

The transducer is the "doing" element of a communications terminal. It is the interface between the external environment of the user and the space-bridging communications system. However, it must be fully compatible with the communication system.

The environment of the user dictates a wide variety of transducers, which will be limited only by the cost — benefit balance to the user. The subsystems of the telecommunications networks are less variable. They have well defined characteristics of a technical and operational nature, a probabilistic behaviour, capital and standardization inertia and planned innovation, which are all a part of system design compromises and trade offs. Even the simple on-off action of a telegraph key requires more than a pair of copper wires to span Canadian distances.

Transducers must respond to loud or soft sounds or voices, to bright sunlight or to much lower light levels. The transmission network parameters are much more closely defined, and either a transducer output must be such that it falls within the acceptance limits for the network, or some form of compression, limiting or amplification, must be provided by the transducer, network-terminal combination. Consideration for personal safety and property must be paramount. The communication network being common to all users must be protected from abuse in all transducer applications. Speed, accuracy, reliability, maintainability and sophistication are functions of cost, design and manufacturing skills, and of overall system design and operation. The weakest link usually limits the value of the service provided.

Man to Man

The primary man to man communication is essentially audio-visual and by shared space. This implies a physical interaction. The concept of "presence" as an element in man to man communication is also recognized, but not yet defined to suit the skills of the designer. Paper interfaces — a record mode of communication, are traditional and adequate for fact or action transmittal, but are of less value for interaction or negotiation.

The two-way visual mode of communication seems to be the next future requirement.

Laboratory models of shared space environments with the capability of interaction such as shaking hands remotely are in existence at MIT Laboratories today. Real time graphic communication devices are in use in the network. Visual communication has a common language of gesture,

picture or drawing, but the mere printing of speech on paper does little to reduce the barrier of language. Other, more direct means of man to man communication such as extra sensory perception are unlikely within the time frame of this study. We will be concerned, therefore, with matching the human capabilities of speech, sound, sight and touch to the transmission network. Research into human colour perception may allow colour to be transmitted with significant information economies, but will not change the basic concepts of man to man communication.

Rapid and easy access from man to the required man-address in the communication network with a minimum of organizational, group or time constraints is one significant objective. The choice of being 'unavailable' is one essential feature of man to man contact, and to some extent in man to machine communication. What is absent in machine to machine interchange today is the ability to compensate for the effects of wide differences in level, clarity, background noise and other undesirable conditions.

Speech has high redundancy and human memory will fill in much of the information if some is lost in transmission. The eye is much less tolerant of error or distortion but again, the brain will usually perform some interpretation. Machines can only have this capability built in at some cost and to a limited extent, however, error detecting and correcting coding can be used to accomplish the same end. There is a trade off between coding complexity, machine complexity and communication costs which requires a thorough knowledge of each subsystem to arrive at the optimum solution in any particular case. This error correction, however, can only be optimized on an end to end basis.

Man to Machine

This form of communication has two facets. In one the machine provides transient or permanent record interfaces between men, as with a cathode ray tube display or a teleprinter. In the other, man interacts with a machine which is essentially a labour saving, skill, or work enhancing device which may also provide an extension to his memory or information store. Man has decision flexibility and in a man machine system, thus far, man has provided the intelligence and accepted the constraints dictated by the limited capability of the machine.

The input-output speed limitations of the system are limited by the human and are probably about 150 bits per second (b/s) for record information input, and about 500 b/s for direct information receiving although higher speeds may be necessary for scan reading and shorthand input. Man-to-machine language, or coding, is the limiting factor and rapid significant changes are unlikely except with familiarity and frequency of use, based on man's historical failure to cope with any language.

For purely record information, or messages transmitted in the store-and-forward mode, speed constraints are those of the machine and the transmission medium, and constitute an economic choice at any point in system evolution. The need for recheck accuracy prior to transmission, which is dependent on the reliability of the man-machine

system, may also be an important factor (as in preparing and checking a tape off-line). Once the tape is prepared and corrected, the controlling costs will be transmission charges and machine cost per second.

Some form of man-machine dialogue will be essential in all but the simplest applications. Growing business use, followed by a following domestic demand within 10 years will lead to extensive random use of a variety of man-machine transducers.

Machine to Machine

There are two significant cases to consider. The first is the closed loop excluding man, when all interaction is programmed action-reaction. The second is when man is part of the information loop and inserts his control external to the machine to machine system.

The significant difference in the language, logic, memory access mechanism, and speed capability between man and machine leads to requirements for transient and record displays. A decision must be made on how these should be related within the total system. The system design decisions are dependent on transmission costs, memory costs and other factors which are more fully covered elsewhere. The sequential input rate of two computers may exceed 300 M b/s. At present such machines are relatively few and point-to-point high speed communication with a limited address selection capability can meet most communications needs.

4.3.1 Evolution of Transducers

Early Transducers and Progress

The telegraph key and its associated buzzers and swinging needle receivers were the first commercial communications transducers. The language developed for the man to machine — machine to man dialogue was limited to about 25 words per minute. Even with today's advances on the basic "shining brass technology", speeds have not increased significantly. The advent of "store and forward" tapes and later of type printers were a logical development of the technology to simplify the operation and increase the speed.

In essence, telephone instruments employing acoustically excited diaphragms with electromagnetic, or variable resistance carbon, transducers have changed little in principle since the early days of telephony.

In visual transducers the mechanical basis of the early facsimile machines and of the semi-mechanical "television" devices limited development until more reliable and controllable electronic means were developed. In the case of facsimile, improvements have not entirely eliminated the mechanical element, but better materials, processes, mechanical design, production and quality control techniques and the use of electronics, have all contributed to a significant improvement and a better value product.

Keyboard machines, either for record or as computer input-output transducers, have progressed rapidly. Page printers at 1,000 words per minute (wpm) are now commercially available and speeds of 150 wpm are common. Direct human input speeds are still limited to 70 or so words per minute.

There are presently over 100 manufacturers in the world making this type of machine, many of them developing the next generation product to enhance or ensure their continuing presence in the market.

The telephone dial is basically a signalling device which extends the control feature of the switching machine to the customer location. The tone dial is a more elegant device which can perform the same job faster. In addition, it can serve as a good basic source of numeric input data for end-to-end control or man to machine information transfer.

The importance of man to man transducer development is well illustrated by the progress made in the design and manufacture of the telephone set itself, as a vital part of the total voice communication system. Design improvements have allowed significant savings in the distribution network. The use of this universal interface has enabled manufacturing economies coupled with a high level of quality control. This, in turn, allows savings in systems design while still maintaining the same quality of voice communication.

Today's Transducers

Any changes in transducer technology which will have a significant effect within the next 20 years must now be known. People can learn, but for the skills to pervade the total environment takes a generation or so. The ability to drive cars was a recent example. The first moves come in the business world where economics of competition force the use. The paper oriented society will continue, but the present business trend towards other forms of data storage will accelerate. Microfilm techniques have advanced rapidly, as have all forms of paper copiers. Calculators are another area of rapid advance; they are becoming smaller, cheaper, more versatile and therefore more readily available as an alternative to larger common use machines. As with copiers, those types which have the ability to interface with the telecommunications network are likely to have a significant advantage.

The use of man to machine transducers as tools is already important. The light pen used by automobile designers to make changes to three dimensional displays of auto bodies, is a typical example. However, the computer is the real tool in all these applications — one transducer is merely the activating element but the display device is the visual feedback transducer which enables man to check and evaluate his work. Such display transducers are already a most significant area of research and development activity in North America, Japan and Europe.

The telephone is the most universal man to man transducer today. With the tone dial input and computer voice answer programs for output, it has the potential for sufficient man to machine communication to complete a high proportion of day to day transactions. The tone dial

environment thus created for many diverse uses must be universal and standard to have the best social impact.

4.3.2 The Future of Transducers

Existing Barriers

Apart from the "presence" or "shared physical space" concepts, which require formidable studies of man himself, the 20 year future should see many of the existing economic barriers removed by technological advances. It has been said that the key to the future of face to face visual telecommunications depends on the development of such devices as the silicon target camera tubes — essentially a problem of manufacturing technology which is complementary to the skills needed to produce large scale integrated circuit devices for a host of other electronics applications.

These developments depend on the capital, manpower and effort behind a dedicated research and development program. This presupposes a viable industry capable of sustaining such an effort. Once the breakthroughs have been achieved, entrepreneurial activities will point the way to a variety of uses depending on the existing or created needs.

Of more long term interest, efforts are being made to meet man's need of freedom of movement often referred to as "the tyranny of the baseboard outlet and the telephone cord". This requires two technological breakthroughs; much lower power requirement, which solid state circuitry will probably achieve, and radio spectrum space which can be stretched by "screened" environments or by reuse of the available spectrum by automatic selection and privacy coding. If "loss of naturalness" can be tolerated, vocoder principles can be used to greatly reduce bandwidth requirements. The latter approach is the subject of intense study and at present can reduce a voice channel by a factor of 30 times.

Such developments as remote diagnosis of illness, text editing of a typist's output and on line translation of language are subject to economic, sociological and technical barriers. If the need is sufficient, they will be perfected. The solutions lie less in the realm of transducers than in computer software technology which is a relatively new science.

Systems Relationships

The vital relationships which have so far existed between the transducer and the space-bridging, communication system can be moved to another plateau by additional digital techniques. The special needs of particular users will, as in the past, be met by new services. The need to prevent accidental or deliberate abuse of the network will still persist. (Abuse here means the addition of noise, tones, and potentials which adversely affect the intended operation and safety of the network and cause impairment to other users.) Transducers will become more complex, and the network control and information conditioning parameters may be more, rather than less critical, if the network environment is to remain secure and usable for all.

Probabilities and Time Frame

Alphanumeric display devices for general use are a probable development in the next five years. These will be much less costly and communications demanding than cathode ray tube devices and will likely speed the onset of the chequeless society. The input device for variable data will probably be the tone dial telephone because of its simplicity, cheapness and standard availability.

The needs or capacities of people for information input-output will probably remain restricted by their social and sensory capabilities. Machines have no such constraints and management tools of all kinds will place major demands on innovative technology and on communications.

There is always the possibility of a second Shannon or Shockley and a new breakthrough. However, the results of their work in the late '40's is only now beginning to have a significant impact. Any presently unknown concepts are unlikely to have a major effect before 1990.

Future Transducer Costs

For man's two-way voice needs, little reduction in terminal costs are expected, but with the use of LSI's many additional features can be provided at minimal cost. For visual terminals, significant cost reductions will be possible during the 1975 to 1980 period. This will allow for widespread use of visual services. Data terminals as they are known today can be expected to become an integral part of the voice terminal. A complete data transmitter has already been built in the laboratory on a single IC with associated low cost implications.

4.4 MOBILE COMMUNICATIONS

4.4.1 Penetration of Integrated Circuits into Mobile Communications

Monolithic integrated circuits (IC) now have high reliabilities and are economically suitable for large volume use. They are mostly used in digital circuits. Mobile communications equipment has considerable linear and analogue circuitry and IC's have not supplanted assemblies of discrete components in meeting all circuit requirements competitively. IC's have found some use in personal receivers where size is important. During 1970-1975 there will be a great upsurge in the use of both IC's and digital circuitry in mobile communications equipment.

Medium scale integrated circuits (MSI) and large scale integrated circuits (LSI) should expand rapidly into the mobile equipment field about 1980.

An obvious target in the land mobile field is a personal receiver or transceiver on a single chip.

4.4.2 Penetration of Computers into Mobile Communication

Cost reduction in memory and logic have led to an increased use of small computers in on-line applications. Mass production of computers and LSI will increase this trend.

Probably the most important land mobile communications application of computers is to public safety services. Computers will maintain updated status of units and people, make decisions for dispatchers and route information to selected recipients.

Commercial radio service provided by land mobile facilities will be similarly served. Some routine dispatching will be done by computer. The computer will locate the vehicle nearest the address, check its inventory and dispatch the driver via teleprinter. In addition, it could control inventories and invoicing.

Access of land mobile units to central data files or banks is now technically feasible and likely to become available shortly. This use of radio channels is not yet authorized and the cost versus the demand is not resolved. Ultimately, a channel dedicated to this use will be needed. About 1990 there will be general use of small mobile computers that decentralize some functions and communicate with a larger central computer. Direct voice accessing of computers via radio link will emerge. There are many problems, but computer access by voice, using a concise, simple vocabulary, may be possible within 10 years.

Take-off, landing, navigation and avoidance problems in air traffic control present a need for better systems to provide precise and rapid position location, velocity control and updating of information on a sector and area basis. Such systems will require computers which will make use of improved inputs of information, provided by air, ground and point to point data links. These same facilities will be used for the transfer, recording and updating of critical information connected with the flight, operation and control of the aircraft.

Computers are already the heart of passenger ticketing systems. These receive input and provide output information through a ground communications network. The use and magnitude of such systems will rapidly increase to cope with the ever-increasing amount of passenger traffic which has to be handled.

Computers are being increasingly used in weather data recording and reporting systems. Low speed, 75 baud, circuits, are being augmented by high speed, 9,600 baud, circuits. These also make use of the ground communications networks for the collection and distribution of data.

Problems associated with passenger, baggage and general load routing and control, lend themselves to computer recording, accumulation and direction. Such systems are not a direct load on the outside communications network as they are generally integrated into the airport internal communications facility.

4.4.3 Penetration of Digital Signalling and Logic into Mobile Communications

The advantages of digital communications include the following; data signals do not require conversion for transmission. Digital transmission has the advantage that it can be made less susceptible to noise in the transmission path by coding techniques and regeneration of pulses before coding. Improvements in reliability and economy are closely related to those in semiconductor and integrated circuits. In mobile communications, digital transmission has been chiefly used for selective calling. However, transmission of data to and from mobile units is coming into use. Conversion of voice for digital transmission over radio is as yet impractical because digital transmission requires more bandwidth. Redundancy removal techniques will help reduce the bandwidth. Maturing of these techniques will result in widespread use of digital transmission for all signals in the 1980's.

Of the schemes for reducing the bandwidth requirements Vocoders and Electronic Speech recognition appear to have the greatest potential. It could find use in police systems as it has inherent privacy. With present technology PCM (pulse code modulation) bandwidth requirements for voice transmission can be reduced by a factor of five, but the requirements are still three times those of unprocessed analogue transmission.

The automation of many reporting, recording and control functions, in connection with air traffic operation, is accelerating the need for a multiple purpose data link between the aircraft and the ground. The rapid development of economical sensors and techniques for human interface with digital systems, make such a data link practical. The adoption, however, is highly dependent upon many operational and integrational factors, which, it is hoped, will be resolved in the next five years, permitting implementation of digital data link systems before 1980.

4.4.4 Penetration of Frequency Synthesization into Mobile Communications

Efficient use of land-mobile frequency bands requires that each mobile unit be capable of operation on a larger number of frequencies. Public Safety systems require up to 12 channels in a large urban area. Urban transportation vehicles will need multichannel capability, as will expansion of mobile telephones and the cell organizational concept.

These needs cannot be met by current techniques and frequency synthesization and associated refinements will come into use by about 1975. While used in military equipment and air-to-ground communications, economic application to land mobile service awaits technological development.

The need for added channels for air-ground communications will be accomplished by channel splitting. This is made possible by improvements in frequency stability. Implementation of these techniques depend upon present equipment becoming obsolete. However, the urgent need for added channels will necessitate adoption in the next decade.

4.4.5 Penetration of Printers in Land Mobile Communications

Compact pager-printer units are available for vehicles. Small size, high reliability, resistance to shock and vibration, and the low current drain essential to mobile service are made possible by available integrated circuits.

New designs allow print-outs of 100 words per minute in a vehicular environment and minimize the effect of noise impulses on message error rate. Present costs limit use to applications where communications must be recorded such as police and railroad. It is predicted that design improvements and larger scale production will bring the printer within reach of most mobile radio users by 1975.

4.4.6 Penetration of Slow Scan TV into Land Mobile Communications

Pictorial information can be transmitted over much narrower frequency channels than the 6 MHz standard NTSC bandwidth. The bandwidth needed depends on the number of frames to be transmitted per second and the desired resolution of the picture. A 3 kHz voice channel of a two-way radio system can be used if some blurring is permitted or the subjects are fairly stationary. Further development is required before costs become low enough for large scale use. It is anticipated that first applications of slow scan TV to mobile communications will be by law enforcement agencies.

4.4.7 Penetration of Active Antennas into Mobile Communications

Antennas in which diodes or transistors are integrated with the radiating elements are practical and the concept opens up new horizons in small antenna research. It is expected that arrays of integrated elements will be used in mobile communications where small size is critical.

4.4.8 Penetration of Repeater Types into Mobile Communications

Heterodyne Repeaters amplify a signal and retransmit it without demodulation and remodulation at audio frequencies. The signal from a mobile unit can go through several such repeaters consecutively without degradation of the audio information. This has advantages of economy and spectrum conservation. Selective use of the system in Canada may help combat frequency congestion.

One-Frequency Repeaters amplify an incoming signal and simultaneously retransmit on the same frequency. The techniques involved are very critical of adjustment and the one-frequency repeater is unlikely to revolutionize the industry. It will probably continue to be used only for special applications.

Vehicular Repeaters are vehicle-carried repeaters that can automatically retransmit signals between low-power portable radio units and their associated base stations. The approach is technically feasible and results shown to be satisfactory. System designs are being refined and implementation simplified. Problem areas include activation

procedures, interference control at repeater sites, isolation of transmitter and receiver at the repeater, power supply filtering in the vehicle, choice of optimum frequency for each application etc. Systems with more than one mobile repeater have to be designed so only one repeater is activated by a portable communicator at one time.

4.4.9 Penetration of the Use of Satellites into Mobile Communications

Technically, land mobile stations can use satellite repeaters on the mobile frequency bands. Widespread interference across the country could result if the mobile bands were used in this way. Narrow beam antennas could restrict coverage to a city-size area. In the land mobile area, satellite repeaters would probably be most useful in providing long distance point-to-point links for widely spaced base stations and for wide area coverage of ships, aircraft and land vehicles under disaster conditions[8]. Various satellite schemes for navigation of and communication with, aircraft have been proposed. These systems could also have application for marine navigation and communication purposes. Such systems still require much development work and probably will not be completely defined and operational before the 1980-1985 era.

4.4.10 Implication and Penetration of Specific Techniques Applicable to Spectrum Conservation

New uses for mobile radio and new concepts for meeting the needs of private and public business are accelerating the demand for more frequency spectrum for this type of service. Some of the technological advances that will make new uses possible have been described.

In the following, a number of methods are reviewed for making more effective use of the spectrum already assigned. These include such techniques as channel splitting, cellular communications, trunking, shared systems, multiplexing, modulation techniques, selective devices, computers for geographic allocation, multi-receiver pick-up and transmitter synchronization.

The general conclusion is that much has already been done to make the most effective use of the assigned spectrum and a point of diminishing returns is being reached. It is obvious that the burgeoning use of land mobile communications will soon result in full utilization of the presently allocated spectrum. For ordinary growth, consideration must be given now to the allocation of additional spectrum space.

(a) Channel Splitting

The manufacturing industry, through advances in technology in solving problems of frequency stability, spurious radiation, deviation control, selectivity and non-linearity, has provided for a more efficient

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[8] "Innovations and New Concepts in Mobile Communications". D.K. Clark and L.G. Schneller, October 1969.

use of the radio spectrum assigned to the land mobile service. The solution of these problems has permitted the adoption of narrow band channels on the basis of splitting existing channels two for one.

Factors mitigating against further splitting of channels are as follows:

(i) Equipment prices would become completely uneconomic.

(ii) The deviation ratio of FM transmitters would have to be reduced to a point where the suppression advantages of FM would be lost.

(iii) The use of digital transmission would be inhibited as, in general, its requirements are for a wider channel rather than a narrower channel unless drastic changes take place in the current state of the art.

(iv) Increased numbers of more closely physically-spaced transmitters in a given area would lead to greater problems of intermodulation interference. Immunity to impulse noise having been seriously reduced, would lead to still greater problems in the interference area.

The above considerations make it unlikely that further channel splitting will be possible on this continent within the next ten years.

(b) Small Zone or Cell

It has been predicted that by 1990 each individual could have his own personal radio-telephone. The demand for channels, based upon present day techniques, could not be met.

High capacity system approaches have been proposed using limited sized zones for the radio coverage. Using short-range base stations it is possible to re-use the radio channels several times in a major area. The use of frequencies in the microwave region would not only more precisely limit the range but would also provide for a larger number of channels than are required.

The main problem to be solved in small zone approach is the real-time switching of zone and frequency in use as the mobile or portable unit moves between zones.

(c) Trunking (or Concentration)

Trunking or concentration implies that a large number of users have access to a small number of channels. The user chooses any channel that is vacant either manually or automatically in the switching system. The Improved Mobile Telephone System now in use in the USA is an example of trunking or concentration system. The small zone system discussed in the previous section would also employ the trunking concept. There is little doubt that trunking or concentration has wide application in the common carrier mobile telephone network. The trunking or concentration concept does not however represent a universal solution for all

users of the land mobile radio services. In systems using short message, high density number of calls, the connection time becomes a limiting factor in the effective efficient use of the spectrum. The many factors involved are discussed at length in Appendix D.

(d) Shared Cost Systems

An objective of advancing technology is to bring communications to the largest number of enterprises which may benefit from it. There are many small enterprises which could benefit from land mobile service, but do not require the full-time use of a clear channel. Maximumization of utilization of a radio channel in this case is always achieved by having several such small organizations share time on the channel. There is a technique of use where there may be several dispatchers having access to a shared frequency, each one being selectively signalled by the use of coded squelch. In similar manner, the use of coded squelch in the mobile units avoids the nuisance of messages of concern only to co-channel users.

The base station may be owned and operated by the users on a cost sharing basis or by the equipment supplier on a rental basis. New technology will be directed toward improvement in privacy between common users.

(e) Multiplexing

Multiplexing may be used in the land mobile service for specialized applications. An analysis of all the factors involved however indicates that an increase in spectrum efficiency would not be obtained by wide applications.

(f) Selective Devices

With the crowding of the land-mobile spectrum, adjacent channel selectivity and receiver front-end selectivity has increased in importance. As a result, the art of crystal filter design has recently advanced very significantly. An RF crystal filter is now available which has 17 dB selectivity on the adjacent channel in the high band. These filters are essential to multi-channel mobile telephone radio equipments or in other applications where adjacent channel operation is necessary in the same location. These crystal filters are also useful in combatting receiver intermodulation problems.

Titanate ceramic resonant elements have been commercially available for some time and have found application as IF bandpass filters. Another device recently announced is the mode-coupled monolithic crystal filter for improved IF selectivity. Four such filters collectively exhibit a sharp skirted bandpass characteristic and do not require tuning adjustment.

There have been steady advances in the technology of selective devices for application external to the radio equipment. These developments are mainly in the area of bandpass filters and multi-couplers to enable the sharing of one antenna by many transmitters and receivers.

In the years ahead, attention will continue to be directed toward improvements in selective devices and we will see integrated circuit technology employed in new ways to make tenable the spectrum we already have.

(g) Computers for Geographic Location

Through a careful analysis of the service areas required by various users, traffic requirements etc., it is possible to assign the same channel at several locations within the same metropolitan area.

By means of coded squelch signals and making maximum use of the FM capture effect, the mobiles close to one base station can operate without serious interference from the other base station(s).

For example, the municipal vehicles of one borough share channels with another borough when neither are likely to operate beyond their own boundaries or the frequency loading is light.

As frequency crowding in urban areas increases, geographic sharing becomes more prevalent as it has in large cities in the USA. To minimize interference, optimum selection of locations and channels is made from a wealth of information which is readily stored in a computer.

The computer is most useful on problems related to frequency assignments. One of these is intermodulation analysis in which all the transmit and receive frequencies in a given area are examined to determine the probabilities of generating interfering IM products. This practice is in use now and will require refinement in the years ahead to speed up the selection of a suitable channel. The computer can also be used in geographic assignment of tertiary channels (the so-called 15 kHz split-split) using a program which allows closer separations than necessary with co-channel operation.

Ultimately, the high band must go through an evolutionary change of channel assignments so that the advantages of spectrum utilization through pairing can be realized. A computer will be of value in this procedure as well.

Future technology will involve further work in software so that the program more nearly fits the real life situation in the field.

(h) Multi-Receiver Pickup

The purpose of a multi-receiver pickup system is to increase the range of mobile or portable equipment whose output power is usually less than the base station transmitter. By strategically locating individual receivers throughout the urban area the talk-back and talk-out range can be equalized.

A voting system is almost synonymous with the multi-receiver system to ensure that only the receiver having the best signal-to-noise ratio is connected to the land based party to the conversation. Multi-receiver systems have found application in mobile-telephone usage and

are now being used to extend the talk-back range of low powered, hand carried, two-way radio equipment used in other services. Because of the low power, interference generating capabilities are minimized and, in this respect, the system aids spectrum conservation.

Improvements in the voting system hardware will be the direction of future technology as recent improvements in portable products has accelerated the demand for them.

(i) Transmitter Synchronization

Just as multi-receivers will extend the range of portable transmitters, multi-transmitters will extend the range of portable receivers such as those used in radio paging. In order to ensure continuous coverage of a metropolitan area, it is necessary to place the transmitters so that generous overlap areas occur, giving rise to interference problems. When a mobile radio receiver receives simultaneous signals from two co-channel transmitters, an interfering beat note is detected with a pitch equal to the difference frequency between the two transmitters. With frequency stability elements common to land mobile equipment, the pitch of the interference varies widely with time and temperature and renders the systems unacceptable.

Some systems transmit the same message sequentially on the two transmitters. This cuts in half the capacity of the system and is impractical where larger numbers of transmitters are required.

Recent technology has given us high stability oscillators which enables frequency control to within a few cycles per year and permits multi-station operation with minimum interference internal to the system. Synchronization of the transmitters from a common source has been proposed and in due course may be available commercially.

(j) Modulation Techniques

Much experimental measurement and objective testing has been done on the evaluation of modulation techniques most suitable for use in the land mobile and marine higher frequency bands. Wideband frequency modulation shows a distinct advantage in the presence of impulse noise (which is a continuous problem in the vehicular environment), but it is expensive of radio spectrum. The advantage of FM improvement reduces rapidly as the frequency modulation index decreases. The commonly termed systems are listed herewith in order of superiority.

1. Wideband frequency modulation.
2. Narrow band frequency modulation.
3. Sliver band frequency modulation (6 kHz bandwidth).
4. Single sideband AM.
5. Double sideband AM (6 kHz bandwidth).

Any simple application of pulse modulation techniques appear not feasible. This is due to the frequency space required for pulse code

modulation. Pulse amplitude modulation requires too great a degree of separation between successive pulses (to avoid crosstalk), to make it usable for this type of service.

In summary, inherent in narrower bandwidth systems is greater degradation due to impulse noise. The current indication is that no improvement in spectrum utilization can be expected from a change in modulation methods.

4.5 DATA STORAGE AND PROCESSING

The imminent need from a telecommunications standpoint will be for increased channel utilization — higher bit rates and lower error rates — resulting from the greatly increased computer-computer communication. To meet this need will require improved signal processing techniques. But we do not have to wait five or ten years for these. Much of the technology already exists in this country and was obtained in both government laboratories and in industrial concerns with the aid of government grants mainly through the Directorate of Industrial Research controlled by D.R.B. This advanced technology can be adapted for commercial use with but little effort when there is an adequate demand for improved service. This is one area where the capability clearly exceeds the requirements, perhaps so much so at present that there is little incentive to advance the state of the art still further. Low-speed communications, primarily connecting remote terminals to a time-sharing computer, will increase too but its growth rate may be smaller.

The many advantages of pulse code digital transmission may make this the usual system on many or all common carrier lines in 20 years. It would make the same circuits eminently satisfactory for normal voice or data communication and in the long run may be more economical than having to provide different lines of different quality requirements. Various systems of time-division multiplexing can be expected to be in common use.

Improvements in the computers themselves will be largely in the man-machine interfaces. As computers become easier and more attractive to use, the number of subscribers to a computing service will increase. The next five or ten years will see the largest relative growth in this area; later, the influx of the decentralized minicomputer will gradually take over, at least for industrial applications. Towards the end of the second decade there may be a trend toward extensive consumer use of computer services in the home. This will again provide a need for low-speed low-cost data transmission.

Improved computer inputs will come from: simpler computer languages; optical character recognition, both document transcription and reading of handwritten messages; voice recognition. Output devices will include: cathode ray tubes; flat electroluminescent panels; computer-spoken words and probably facsimile devices. Interactive displays will be commonplace.

Within the computer, the major advance in the past decade seems to have been the development of time-sharing systems. Undoubtedly this

progress will continue far into the future. It is hoped that adaptive and programmable logic will make significant inroads in the next two decades. Memory cost will doubtless decrease, regardless of which forms are used. Large semiconductor, especially MOS, memories are already available, both RAM's (random-access memories) and ROM's (read-only memories); this area will show explosive growth. Large-scale integration will become practicable for many other applications as well. These three factors (logic, memory, LSI) will provide for even more flexibility in the small computer and make the decentralized facility still more attractive. Both small and large systems will benefit from improved reliability and redundancy techniques.

5. SYSTEMS IMPLICATIONS

GENERAL

In Section 5 each of the contributors or collective contributing organizations, i.e., Common Carriers, Electronic Industries Association of Canada, Broadcasting Authorities, etc., has considered the overall implications for the networks, media and systems with which they are familiar. Technical people tend to be "close to their own particular fields". However, the study has resulted in discussion and mutual questioning of contributions. This has been chiefly on technical matters and aimed at technical agreement and consistency.

5.1 THE COMMON CARRIER NETWORK

5.1.1 Introduction

In Section 5 of the report the various requirements of the common carrier network will be explored. General trends of user needs and their effect on the network will be discussed with respect to network technologies available and the network operation.

The rapid rate of introduction of PCM Short Haul Transmission Systems in Canada by the common carriers, has likely set the stage for a communication network using mainly digital subsystems. Economies of PCM transmission systems are expected to be further improved by the carefully planned integration of time division switching into the present common carrier network yielding a versatile general purpose communication system. In order to ensure proper development of this system, all of its parts must be designed with regard to total system performance and economy.

General Trends

It is expected that in the future common carrier communication network, the supply and retrieval of information will still be man's need although more ways of enlarging his "communications space" will be found and perfected. If this space is handled by a general purpose switched network, the advantages for operation as well as from a user's point of

view are many. It is the only economic way to make medium speed data and facsimile channels potentially available to everybody on a dialled up basis. Limited access to information breeds partitioning of ideas and inefficient use of resources. Hence the communication user requires as broad and unrestricted access to other users as possible. We should not attempt to partition or sectionalize communications by network concepts. For example, technological advances in written and speech recognition circuits will very likely mean that computers will converse with man in the users tongue or in some visual form rather than in the present day machine instructions. We should also not restrict our model of the communications network to today's concepts as this occludes certain future concepts. We should direct our thinking to finding a flexible model capable of meeting a user's total requirements to obtain or impart information. Finally, we should be mindful that we will be called on in the future to provide forms of communications not provided today such as the senses of smell, touch and taste if we can hope to decentralize man from the limitations of a physical centralized environment.

Demands on Technology

The demands on technology in Canada in the next two decades will certainly be substantial. Although we can predict from past trends some measure of the future, Dean Myron Tribus currently on leave from Dartmouth's Thayer School of Engineering warns that: "things will happen sooner and on a larger scale than most of us now think likely — don't conclude not in my lifetime". Similarly a note of warning from William Haber, Dean of the College of Literature, Science and Arts at the University of Michigan predicts that by 1990 fifty percent of the work force will be engaged in jobs not in existence today and the majority not yet conceived.

For Canada to meet his demand with answers from true Canadian technology, increasing amounts of research funds must be available. Work will of necessity be mainly "mission oriented" to fields where additional knowledge is required in order to enable the technological evolution or breakthroughs to be achieved. At the same time, the technology must not be regulated to the point where newer technologies are stifled.

Network Compatibility

The Canadian Common Carriers must ensure overall network compatibility within Canada, with the remainder of North America and the rest of the world. As operating companies directly involved with the network design and operation, the individual common carriers are the only ones that can ensure this working compatibility. Close cooperation and working agreements between all Canadian operating companies on product applications system designs and operating matters is currently the key factor to the success in overall Canadian common carrier compatibility. Different geography and operating conditions will mean that different common carriers often will use different components and procedures in achieving a common national objective. Close cooperation with the Bell System and the work organization ITU ensures compatibility on a North American and world wide basis.

In undertaking the development and introduction of new services it is important that they be conceived, designed and introduced so as to ensure complete operating compatibility with the existing network. Every part must work with every other in the complete communications network and those responsible for the design development and manufacture of the component blocks must be knowledgeable of the entire network. This knowledge allows the best use of Canadian telecommunication resources.

A telecommunication network is a two-way service and unlike other utilities, the customer's input must come out in the same form that it went in. Output terminals must be compatible in all respect to the input terminals. The concept of the "total system approach" is a key one, as any new service of the future will require interconnection to all parts of the country, the continent and the rest of the world.

Impact of Innovation and Modernization

Innovation and modernization of the common carrier network are and will be the basis of maintaining high quality efficient service for the Canadian communication user. In essence, innovation is the process through which modernization is achieved and it is only through this modernization that increased productivity, reduced capital costs, improved quality of service and network flexibility to customer needs can be achieved.

The common carrier's past innovative effort has been large and rewarding. Its future must be even larger to keep pace with the technological advances possible in the next two decades. The rapid growth of technology can be appreciated by considering the following. A scientist today is not amazed that a computer can do for him in a few seconds what would have been several lifetimes of work less than two decades ago. Nor is a communication engineer likely to be greatly impressed by being able to provide 100,000 long haul circuits through a single waveguide when less than three decades ago it was a real achievement to obtain 12 circuits on a cable pair. Indeed when we consider that 90% of all the scientists and engineers that ever lived are alive today, the full role that technology has played in the past few decades and will certainly play in the coming two decades is seen to be enormous.

The user's needs dictate more clearly than ever that the transmission network of tomorrow must be flexible and transparent to all types of information transmission from voice through colour pictures and beyond if necessary.

The planned innovation necessary to accomplish this goal is greatly aided by the carriers working closely with the manufacturers where the resulting interaction produces more seasoned ideas than could be forthcoming from the two working individually. It can be argued as well that we in Canada with our limited technical resources can scarcely afford anything less than this close knit approach.

Rate of Innovation

New technologies are introduced where their use can provide an improvement over existing technologies in flexibility, operating costs, transmission performance or where existing technologies cannot technically fill a new service need. The rate of innovation into the network is not limited by the ability to adapt new technology to existing equipment. The communication common carriers in Canada have been in general pioneers in every branch of communications. Everything that is technically possible however, cannnot be pursued with limited capital resources. A great number of services and technologies if introduced at all must measure up to the yardstick of the marketplace — the need of the customer and the price he is willing to pay for a new, or for that matter, a more reliable grade of service. Inevitably some proposals will fail to measure up to this stern criterion, but this will stimulate effort to find more economical means within the limited freedom of the available resources.

New technologies have, generally speaking, taken a period of 10 to 15 years from conception to full exploitation. This is partly due to the necessary lead time to design and adequately test devices and systems. In today's environment however, systems are planned on the basis that technological breakthroughs must be attained at various stages in the system development. The use of standard building blocks such as LSI's in the system design and manufacture may also tend to reduce this part of the schedule, which may mean earlier availability of system components. The period from introduction to widescale use will probably not differ appreciably from the past. Innovation must be planned, continual and in order to provide service, the incremental solutions introduced may not be the optimum solutions. For this reason, the technology of flexibility must be cultivated in order that systems installed today will permit the exploitation of new ideas in the future without rigid dependence on past preconceptions of the services and facilities that were expected to be required. Because of the high growth rate of the common carrier network in Canada, new technologies can be integrated readily in this way, when they are economically viable. For example, over 150 PCM carrier systems were put into service with the initial introduction of PCM into Canada in 1965.

Manpower Requirements

The need to attract skilled manpower for the necessary operating functions and rising labour rates will force the common carrier to exercise the utmost technological ingenuity in introducing labour saving devices and methods of operation. In the future, automated maintenance will be the largest factor in system viability. Similarly, customer assistance services must be as fully automated as is technically possible to allow for the expected growth of the network in the next decade. In the future the trend will be towards getting functions which can be accomplished by machines performed by machines.

5.1.2 Interrelationships of the Network Subsystems

(a) General

A network makes point-to-point communications economically possible. It is the network that provides both the means of selection and the pathway itself for a communication. That is to say, the network is the combination of all of the various subsystems of transmission, switching and transducers to provide economical paths between the users.

The aspect that makes the common carrier network challenging is its size and the inherent relationships and interdependances of the various subsystems comprising the whole. The Canadian network of almost 10 million stations and many operating companies must work as a unit. It must also be capable of direct interconnection and operation with the remaining North American network of about 130 million stations as well as interfacing with the rest of the world.

The present network, whose basic concept dates back more than 40 years, has proven to be remarkably adaptable to growth and change. Certainly not a rigid monolithic structure, it is an extremely flexible system which is continuously being reconnected in different patterns and operating circumstances to mate with the changing traffic and technology of the times.

The built in flexibility today is no accident as the network was conceived from experience which has given Canada one of the finest communication systems in the world. The flexibility has been necessary from the onset to handle growth and to provide continual rebalancing of the network in terms of traffic and the relative costs of the subsystems which comprise the network.

(b) Economic Tradeoffs In Switching, Transmission, Distribution and Transducers Are Made Continually within the Present Flexible Hierarchical Network

In Section 4.2 of this report mention was made concerning the balance between switching and transmission in the network. This is only one of many tradeoffs which are continually experienced and rebalanced according to the technology available and associated costs. At the present time the distribution of these costs for an individual telephone subscriber in the Canadian network is approximately 7.5% for the station and its associated connection, 37% for distribution facilities, 35% for local switching equipment, 5.5% for tandem switching equipment, and 15% for long and short haul transmission facilities. The more complex station installations found in business such as station hands free operation plus other features can alter the distribution of costs by 50% from these figures. However, when the average costs other than the station set are considered from the standpoint of two callers — A and B in the network, the breakdown would be as follows: distribution (A) approximately 20%, local switch (A) approximately 19%, long and short haul transmission plus tandem switching — 22%, local switching (B) — 19% and distribution (B) — 20%. This balance is currently believed to be the most economic but is continually varying as relative costs of subsystems change with technology.

To realize this economic solution and maintain flexibility the long and short haul facilities plus the tandem switchers are arranged in a five level hierarchical structure of switching which avoids the necessity of directly connecting all tandem switchers with one another. This hierarchy is shown in Figure 9. With this structure many local switching centres are tandemed through a tandem office shown as #4 which in turn along with many other #4 type offices is tandemed through a class #3 office, which along with other class #3 offices is tandemed through a class #2 office and so on. There are currently 2 class #1 offices, 6 class #2 offices, 27 class #3 offices, 167 class #4 offices,

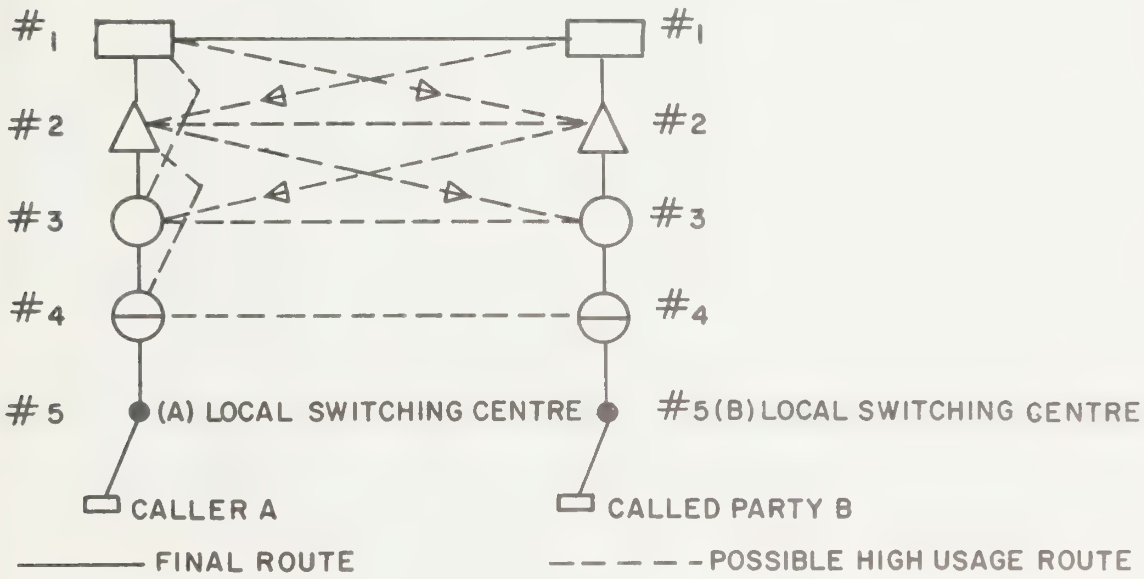

Fig. 9. Five level hierarchical structure of switching.

and over 4,000 class #5 offices in Canada. The solid line indicates the final or worst case route through the hierarchy and including the two local distribution loops, the call could take up to 11 transmission links for the complete connection. Alternate routing however, has been introduced into the hierarchy and various high usage routes shown dotted would be selected by the various tandem switchers on a priority basis. The solid line or final choice would have a probability of occurrence of .001% per call. In figure 9 high usage routes are designed to cross from left to right on the same level or down to a higher number office. This flexibility of routing as well as providing economies through the mixture of direct and heavier volume tandem transmission facilities also greatly reduces the chance of path blockage in the network. The provisioning and design of the facilities in the network is complicated by this alternate routing feature. Each transmission facility including the local distribution and the terminating device must be designed to strict signalling and transmission standards for its particular application in the hierarchy. The total network facility formed must provide a degree of uniformity of transmission quality regardless of the number of transmission facilities used in the connection.

The network must also be capable of controlling the establishment and disconnection of transmission paths. Supervisory signals are used between switching machines to provide this real time control. The network must also be capable of providing control for traffic pattern changes such as those that occur during the peak busy hours in one locality or geographical area. This type of control is used to restructure the network to meet the varying loads which occur. This kind of control must also be available to restructure the network during unpredictable changes in the network such as the accidental outage of a long haul transmission facility route.

(c) Network Economies Are Achieved Through Large Scale

The yardstick for measuring the performance of any network is its success in providing satisfactory point-to-point communications at the optimum cost. The network which has the highest volume of traffic and largest cross sections will be the most economic. There are three principal factors which can assist towards this end.

The first of these is optimizing the transmission — switching arrangement in the network. As transmission facility groups become larger through normal growth and extension of alternate routing and other network design concepts, the transmission facilities are capable of carrying more traffic per individual facility. Growth also permits additional direct transmission routes to be established resulting in fewer switched connections, fewer transmission facilities in tandem and hence lower costs. The hierarchical system fills the present requirement and has built in flexibility for future evolution.

The second aspect is the ability to maintain high utilization of the network at all times. With singular type services such as telephone, TWX, Telex, Data or others by themselves, the network will exhibit traffic peaks dependent on the service and the user and the network must be designed for this peak. To some degree this can be influenced by offering time price tradeoffs of reduced rates in the historical non-busy hours. A much better equalization of traffic can be accomplished by the mixture of all types of services on the network where individual non-coincident busy hours provide a statistical time usage mix. Both of these factors have been utilized in the present network by rate structure and multi-service usage of the network.

The last factor related somewhat to the second is the economy of scale from shared use. Not only are traffic peaks flattened from the addition of other services, but when services other than the regular switched network services are carried by the common carrier, such as network video distribution for the broadcaster, the resultant larger cross section transmission facility provides the same unit cost benefits provided by many hundreds of additional voice circuits. For efficiency therefore, it is imperative that these wideband services be provided on shared transmission facilities to as high a degree as is possible.

The common carrier engineer's job we have said is to optimize the network flexibility and cost. The fact is inescapable that every part of the network is dependent on other parts in many ways. In his attempt

to blend switching, transmission and terminal equipment into this optimum state, he must thus consider all of the parts of the tightly coupled network and synthesize the model within these constraints. It is unfortunate that the largest computers can model only a very small fraction of the total network. Network self-analysis will be built into the network in the future with the network performing its own optimization.

5.1.3 Network Service Requirements of the Future

(a) General — Growth will be High

Having examined the present construction of the network, the question of which services will influence its future will be explored. The household and business markets will be examined.

In order to evaluate the future requirement of the network, it is worthwhile to examine the forecast of growth of the Canadian population over the next two decades, as shown in Figure 10, which must be served by the common carrier network. A unique age distribution exists in Canada at the present time with about 40% of the population under 20 years of age and only 37% of the population in the labour force. This

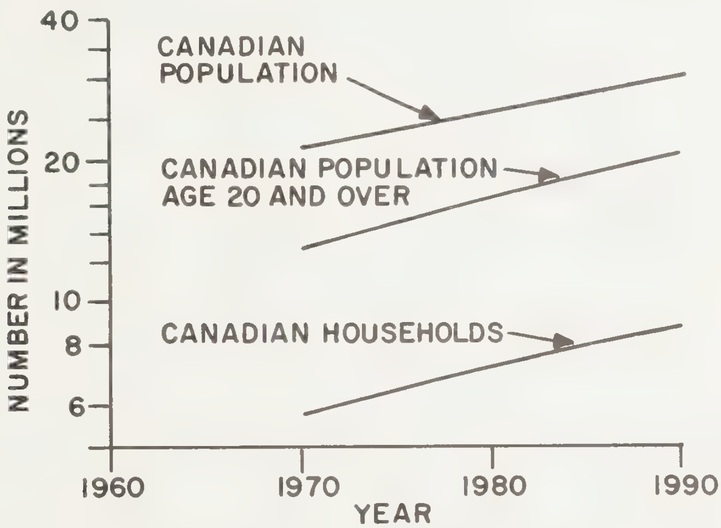

Fig. 10. Forecasts of growth of Canadian population and households.

will shift during the next decade to approximately 30% under the age of 20 and a correspondingly higher percentage in the labour force. The trend towards smaller families in the recent past has of course been responsible for this trend. It will also be responsible for the decrease in the rate of formation of households during the next two decades.

Voice band services will be defined as those audio and data services which will be served on a switched basis. Visual services will also be handled on a switched basis and will include services of higher information rate than are covered in voice band services. Special services will deal with all localized special distribution type services.

(b) Household or Individual Services will Require Many Features on Dial Up Basis

As was seen from Figure 10 the household market will continue to expand in sheer number but at a decreasing percentage of growth.

(i) Voice Band Services will be the Major Requirement

The requirement for two-way voice services will continue to grow although the physical sets, distribution, transmission and switching hardware will change as will the range of services. It can be seen from Figure 11 that the market saturation point is very close in terms of main lines per household, although some growth of additional lines per household is expected. The growth rate of additional stations is expected to follow the trend in number of households over the same period.

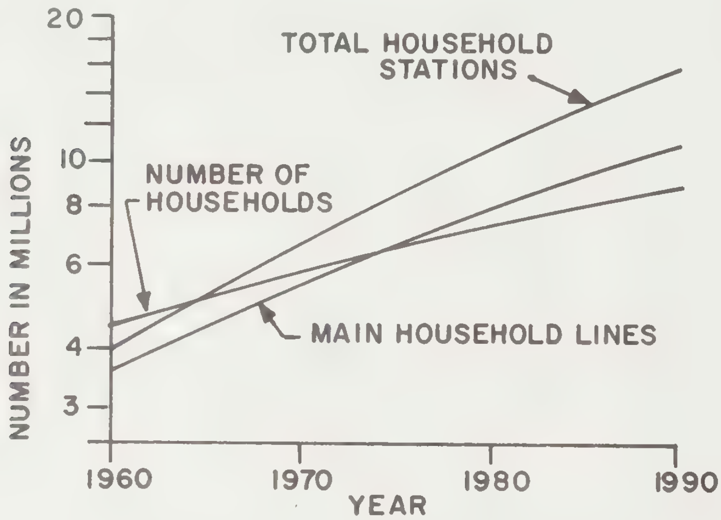

Fig. 11. Two-way voice requirements.

Figure 12 shows the degree of penetration of the two-way voice service in the household market.

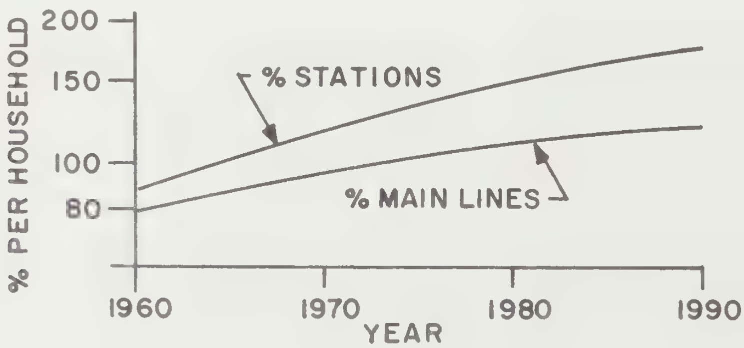

Fig. 12. Percent market attained.

Features which will likely be required have been covered in Section 2.1 of this report as well as Telecommission Study Group 2(e) but will be included here in tabular form for reference.

1970 to 1980

— Absent or busy message recorders.

— Voice answer information retrieval.

— Recorded announcement services.

— Hands free telephone.

— Portable keyboard-printer terminals for remote computer access.

— Improved transmission quality service.

— Integration with public mobile radio service.

— Portable paging service.

— Abbreviated dialling features and automatic recalling.

— Conference calling.

— Call forwarding to another number.

— Alphanumeric displays.

— Customer personal identification.

— Remote control of household appliances, etc.

— Banking services and bill paying by telephone.

— Remote computation ability.

— Unattended alarm service.

1980 to 1990

— Voice recognition computer services.

— Translation services.

— Call Store and Forward Services.

— Cordless telephone service.

— Personal home data terminal.

— Graphic displays.

— Message service by phone.

A great number of the features required will be dependent on an inexpensive data input device such as the tone dial on the telephone. The services listed and other needs not listed but required during the next two decades, will be required in varying degrees depending on the cost of the technology available to meet the demand. As in the past, the business community will probably be the first user for many new services. However, trends toward decentralizing work functions back towards the home during the second

decade coupled with demands from the educational community may provide considerably more emphasis to this sector of the market.

(ii) Visual Services will have Greatest Penetration During 1980's

The advent of two-way videophone services into the network during the mid 1970's may capture a very small portion of the household market during the remaining 1970's. It is believed that considerably more penetration of the home market will be made during the 1980's. The videophone will be likely the medium through which wider band services are made available to the householder. Some of these services which can be expected during the 1980's are tabulated below:

- Visual information retrieval systems.
- Individual visual shopping services.
- Main service by wire.
- Visual educational services.
- Graphic display services.
- Visual two-way interaction with a computer.
- Visual conferencing services.

It is expected that videophone has a potential market of approximately 1% of the household market (approx. 70 thousand stations) by the year 1990. This is a sizable market considering the fact that videophone requires between 100 and 400 times the bandwidth occupied by voice channels on the transmission media.

The much higher costs of videophone and other wideband services are likely to shape the household market initially around other transducers capable of operating over the switched voice band network. Low cost printers or alphanumeric display terminals may thus capture a large portion of the visual display market during the early years where interaction on a visual basis is not as important as cost.

(iii) Special Services will be Required with Selection Capability

Trends over the past few years have been away from true point-to-mass type of broadcast services. The requirement seen in wired music distribution and CATV types of services will continue and enlarge to offer more individual choice in entertainment. Dial selection home entertainment will most certainly be required to some degree by the 1980 to 1990 period, as the trend towards individualism increases. Services required will probably include:

- High fidelity and full dimensional music distribution.
- Special video retrieval for home entertainment.
- Other special user requirements of individuals for the home.

(c) The Business Community will require Greater Interaction and Mobility

The search for more efficient business information systems by the business community will create a market of experimentation, demands for the rapid provision of service to meet competitors, and one of overall general evolution during the next decade. Beyond 1980 it is difficult to forecast the type of business community however, this trend will probably continue until 1990. The re-evaluation and re-definition of operations will probably employ as many new features as are economically feasible from a technological standpoint simply to meet telecommunication needs.

(i) Voice Band Services will be a Major Requirement

A large portion of the requirement will be two-way voice services or services provided over the switched voice band network. Figure 13 gives the forecast of growth for this portion of the business market in Canada.

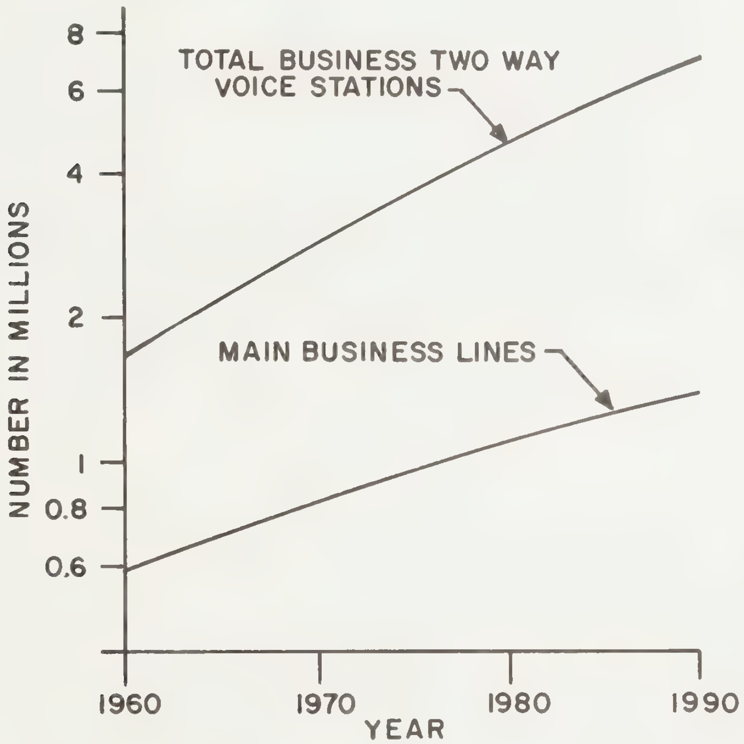

Fig. 13. Forecast of growth of voice band services in the business market.

In addition to and excluding two-way voice stations equipped with conventional rotary or tone dials, a forecast for switched data terminals with speeds up to about 50 kilobits/sec is shown in Figure 14. The present 50 kilobits/sec service is handled on a separate matrix, as indicated in section 4.2 however, during the forecast time frame, it is expected to become a part of the voice band network and is thus included.

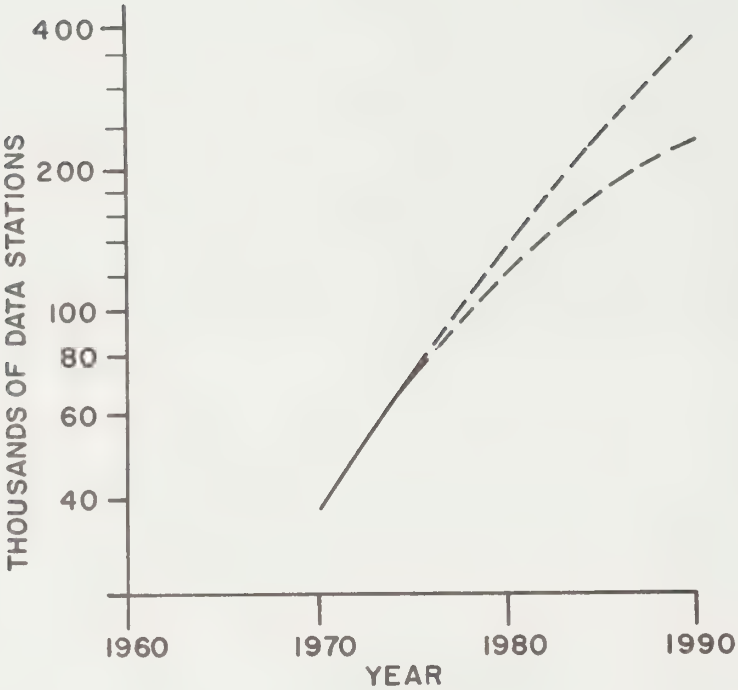

Fig. 14. Projected growth of data stations using switched network.

Because of the lack of early data this forecast can at best be considered approximate and is treated as a band of values beyond 1975. The requirement for 50 kilobit/sec service is expected to be extremely small prior to 1975.

The expected related services associated with the two-way voice and voice band data services are shown below:

1970 to 1980

— Absent or busy message recorder service.

— Voice answer information retrieval.

— Hands free telephone service.

— Keyboard-printer terminal service for computer.

— Fuller integration with mobile radio service.

— More sophisticated pocket paging systems.

— Abbreviated dialling features and recall ability.

— Voice conference service.

— Call forwarding to another number.

— Secretarial service via computer.

— Language translation services.

- Graphic displays for medical, etc.
- Alphanumeric displays.
- Unattended alarm services.
- Cordless telephonewwithin a building.
- Call Store and Forward with translation of speed and code.

1980 to 1990

- Mail services via telecommunication lines.
- Wider flexibility and range of cordless phone, and expansion on other services plus many new services.

(ii) A Wide Variety of Visual Services will be Required First by Business Community

The market for visual services is expected to be relatively large for the business community. Visual retrieval systems for both the educational and industrial sectors will form a large part. Visual real time services for the medical community, for one example, will also be required and will require a wide range of transducers from video to digital and graphic plotters. Audio-visual conference services will complement the transportation market and may further stimulate both markets. The current trend toward faster information transfer, brought about through business competition, will supplement the postal services. Mail services would of course still be the most economic means for slower delivery of large amounts of information in the form of microfilm, holograms or other information stores. A summary of the expected services required is tabulated below:

1970 to 1980

- Educational video retrieval.
- Visual information retrieval systems.
- Audio-visual conference services.
- Priority mail services by wire.
- Visual educational services for instruction.
- Graphic display services.
- Videophone service.

1980 to 1990

- An extension of the above with greater tendency towards mobility of the individual.

The market will consist of many services centred about many types of transducers. The videophone market alone is expected to have penetrated about 6% of the business market by 1990 (eighty thousand stations).

(iii) Special Services Mainly Integrated into Network in Future

Many special services are in existence today serving special needs of the business community. It has been mentioned how these special services integrated into the network allow unit cost reductions for all services. During the next decade, it will be possible to provide the majority of the special private line services on a switched network basis mainly due to similar needs of many users.

5.1.4 The Future Network

(a) General — The Individual's Total Communication Needs Are Best Served by the Common Carrier Network

In the past,point-to-mass type of communication was most economical and lead to an homogenized society. Recently the newer technology which is emerging, allows much greater discretionary choice for the users and is leading away from homogenity towards individuality and associated network requirements.

The preferred communication devices, and hence the network, will be adapted by the consumer to meet his own individualism when and where he wants it. This in itself will result in a wide proliferation of input-output devices in the network and most assuredly in mobility. New technologies have been seen in the past to have been adopted more quickly where an existing medium provided a means for growth and expansion. In the future most interactive devices can use the switched voice band network and the associated service organization as a medium, and can expect faster acceptance and adoption by the users. Similarly in the second decade an increase in capacity allowed by the introduction of the videophone will be available to further stimulate innovation in user technology.

The future evolving communication network is one in which the telephone of today, the computer, and a variety of audio-visual devices are bonded together into one closely interrelated network, which will allow the user ease of interaction and response.

(b) Network Traffic Will Have Increasing Growth Rate

The combined impact of the growth of existing services coupled with the wide assortment of new services, will continue the heavy growth experienced in the past. New technology as outlined in section 4 of this report must and will be available to meet these demands.

Present and future trends for large increases in the number of calls and call duration will require more switching and transmission hardware, as will the continual growth in the number of customer stations in the network. The total expected growth of the existing common

carrier switched networks in Canada for all services including data is shown in Figure 15 for both local and toll type calling. The difference in scale should be noted between the two curves. It should be noted that both curves depart slightly from the classical exponential growth of many countries indicating an increase in percentage growth. Growth

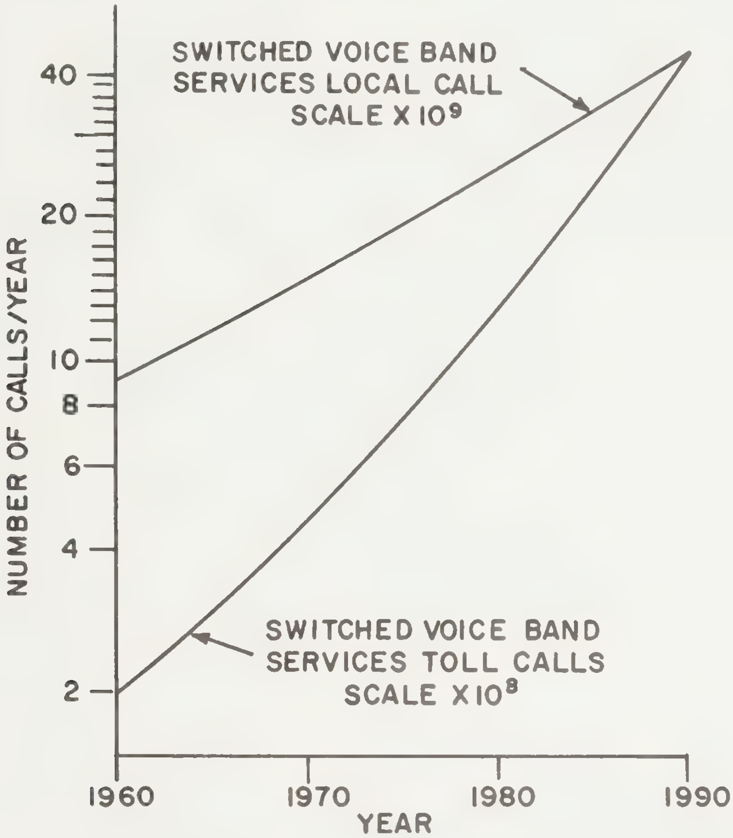

Fig. 15. Expected growth of existing common carrier switched networks for all services for both local and toll calling.

rates for the number of calls for all switched voice band services are seen to be in excess of 10% for toll and 5.5% for local per year. The average call duration or holding time is also increasing at a similar rate. When total requirements including private lines are considered the total growth rates for certain cross sections are in excess of 17%. Systems engineering studies indicate that the network hierarchical structure of five levels will be adequate until at least the mid 1970's. Beyond that point the traffic patterns will have increased to the point where the top rank (the class #1 tandem switchers) can be eliminated. This will be a direct consequence of more traffic and the economic interrelationship of transmission and switching at that traffic level.

(c) The Evolving Structure will Require New Technologies for Growth

For the switched network to adequately serve all of the varying requirements of the future communication market, many of the new technologies outlined in detail in section 4 of this report will be required

Present and future network growth rates will require the use of long haul coaxial cable systems by the mid 1970's and waveguides or laser systems during the 1980's. It is unlikely that satellite circuits will be economic or suitable for message service during this decade on east-west domestic routes. They will however, provide some east-west television facilities as well as services to far northern communities. Switching systems introduced will of necessity all be common control and mostly electronic stored program control during the 1970's. The inclusion of time division PCM switching and decentralized switching into the electronic stored program switchers during the 1980's, will offer additional flexibility and economy. The variety of services will probably make wideband distribution systems economically possible by the late 1970's only for selected population and service densities and may have widespread application for combined total services during the 1980's.

The network must become more and more a system of broad super-highways, access routes, bypass routes, and avenues with adequate over-all traffic control. At the present time, each switching centre chooses its routes based on fixed logic patterns and the availability of trunks to which it has direct connections. The entire network is laid out on the basis of the statistics of normal traffic flow and facilities are provided in sufficient quantity to accommodate this normal traffic. The fixed routing logic for each switching centre is planned to make efficient use of its available access and to minimize the chance of call blockage.

(d) Common Signal Data Control Channel Increases Network Efficiency

Even with alternate routing capability in the tandem switchers it is possible to start out on a call setup, which will be ultimately blocked by a traffic situation in a distant office. This is mainly due to the fact that little knowledge is available to a single switcher concerning the total network. Address information for each channel is presently transmitted via the channel itself, hence the switcher must scan each channel to determine its state of use or signalling information content. The present network has some flexibility in providing special channel routing, but is not truly adequate for all future needs. In addition an economic means of automatic traffic routing during a failure in the network is of great benefit. To meet all of these needs and others, the concept of the common signal data control channel is planned. Starting in about the mid 1970's and completing by the mid 1980's all common control electronic stored program switching systems will be arranged to exchange signalling information for each communication channel over common signal data channels rather than over the individual communication channels. It will then be possible to monitor each switcher's own traffic loads and swap this information with other offices. Offices may then adjust their routing to best suit any traffic congestion occurring in the network. This feature alone is expected to realize an approximate 20% savings in transmission facilities. The better match of the signalling data channel with the speed of the switching machine will also realize greater economies and switching speed. Other features which can be controlled by this means are listed below:

— Variable format for transmission facilities so that many types of information can be sent down a common "pipe" and sorted out at the destination.

— Control of transmission facility group sizes to meet busy hour loads by network reconfiguration.

— Priority and pre-emption information for the network.

— Special billing information for services such as INWATS[9].

— Identification of traffic for off network dialling, interconnection control, special usage measurements at intermediate switching points, etc.

— Network management functions to control the network operation.

— Network status information to indicate problem areas in the network such as congestion, overload and equipment outage.

Signalling and supervision will thus be more of a computer to computer type of control than exists at present.

(e) Lower Hierarchical Order for Network Will Evolve from Growth and Common Signal Data Channel

The degree of network traffic control which will be possible with the common signal data channel concept, coupled with the expected increase in traffic during the second decade, and the desire for much faster setup times of the network will certainly reduce the present hierarchical level by at least one level during the 1970's. If present indications are correct the ultimate structure will be a three level hierarchy by 1990.

(f) Larger Size of Switchers Will Be Economical Because of Growth

Studies indicate that apart from the necessity of stored program common control with time and space division capability for the switchers of tomorrow, the switchers, or more properly the common control central processor, must be much larger in capacity.

With a larger size tandem switcher the trunk group sizes will be larger and greater efficiency can be obtained from the trunk group. In addition larger size tandem switchers mean fewer total switchers and hence a reduction in the number of trunk routes. In certain metropolitan areas where several tandem switchers are necessary, studies have indicated that doubling the size of the tandem switcher would allow up to one million dollars in annual saving in transmission and switching costs. Switchers should be of modular construction with larger sizes to allow for economic growth.

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[9] Inward Wide Area Telephone Service. This is a special customer billing service for billing the receiver of telephone calls.

For local or end office switchers the central processor should be common for as many lines as possible to allow for maximum economy through increased trunking efficiency. This does not imply a single processor. For example, decentralized switching might employ many satellite switchers in buildings and manholes with some limited individual processing capability but with major control provided from one of many centralized central processors.

(g) One Network Is Most Economic and Can Meet All User Needs Today and in Future

The voice band portion of the switched network in operation today can provide a maximum average capacity of about 24 kilobits/sec. State of the art data stations have as yet only achieved about 9.6 kilobits/sec per channel on a switched basis. As PCM carrier becomes more widely used in the network the limit will rise towards a new limit of 64 kilobits/sec per channel. The vast majority of data users today are operating at maximum speeds of 1,200 bits/sec and less, and only for sporadic bursts. The rise in channel capacity will only further reduce their channel usage efficiency unless traffic capabilities of the user are increased or channel subdivision offerings are made to match the users average output capability.

The use of subchannel capacity transmission channels is thus essential and practicable to optimize the transmission and switching capability of the network. The initial provision of this service will be handled on separate concentrators, however, the features will be built into future switchers.

All present and future data needs can be provided by the network. Current offerings on the switched voice band analogue network can provide data users speeds up to 4.8 kilobits/sec and higher. Special matrices in conjunction with the voice band switchers extend this range to 240 kilobits/sec and higher and will carry videophone at 6 million bits/sec which is well above any present data market requirement. With the current FDM facilities in Canada, this approach of providing data circuits over analogue facilities is the least expensive for the forecast data market in Canada. For example, the relative cost ratio for the average 1,200 bit/sec user would be 2:1 in favour of the existing analogue approach at present, and with the integrated circuit data set mentioned in section 4.3, this ratio would increase.

As PCM facilities become more widespread in Canada and the rest of the world, standard offerings expected in Canada will be 8, 64, 256, 1,500 and 6,300 kilobits/sec on a switched basis. This should be adequate for the majority of needs, and much higher bit rates up to about 280 million bits/sec would be available for special users. With an all digital network a form of multiplex equipment will be required associated with each line to process the customer's asynchronous information into the proper synchronism and format for transmission through the PCM network.

Television distribution and live network switching which is performed by the common carrier for the broadcaster, will take on a new

phase utilizing digital transmission and switching beginning in the late 1970's and reaching maturity in the 1980's. Benefits of PCM for long haul video will only be fully realized when all links in the video network are via PCM facilities and PCM switching. This would mean that satellite circuits must also be capable of handling the 100 million bit/sec PCM pulse stream required for video transmission. Satellite circuits should be designed with total system compatibility in mind.

(h) Integration of New Technology with Old Accomplished with Common Signal Data Channel

A major percentage of today's analogue facilities as well as analogue facilities which will be economically added to existing routes during the next decade, will still be in appropriate use beyond 1990. The total transition from analogue to digital will thus be a gradual one extending over a long period of time. Restoration of existing analogue facilities over new routes will also dictate that some future analogue circuits will be provided on the newer digital facilities.

The use of common signal data channels commencing in the mid 1970's will allow the routing of particular services over the newer or older transmission paths in accordance with their network requirements and will thus greatly reduce problems of integration of the two technologies.

(i) Integration of Mobile Radio and Paging Into the Network Is Essential and Requires Additional Spectrum

The use of mobile radio as a form of distribution plant is the only one which ultimately can provide the mobility required by man. The optimum use for the customer can be obtained by fully integrating this service as any other station in the switched network. Ultimately the number of the available channels must be expanded probably at the expense of the television broadcasting VHF and UHF bands. With additional channels and the use of idle channel scan hunting in the mobile units, efficient use of the available spectrum can be made in providing this vital need.

Paging systems must also be expanded and integrated more fully with the network for optimum customer benefit as indicated in section 4.1 of this report.

5.1.5 Operation of the Network

(a) Customer Assistance Will Require Less Operator Involvement

Without considerable mechanization or change in philosophy, it will not be possible to keep up to growth in providing operator long distance, directory assistance and other informational services. Many new technological devices will be required. Systems are being planned to minimize direct operator involvement time on long distance personal service. Similarly, information retrieval systems will gradually replace many of the manual systems employed for information and directory assistance today.

(b) Network Management Will Automatically Stabilize Traffic Patterns

The stabilization of traffic patterns within the network is performed by the use of manual and automatic network management control. By stabilization efforts, the effects of one sector of the network exceeding the engineered capacity temporarily and causing increased blocking throughout the system are minimized during the overload. This function is performed today through several controls such as:

— Cancellation of alternate routing.

— Directional reservation of facilities.

— Traffic overload reroute control.

— Status information displays.

— Dynamic overload control.

— Removal of lower priority work operations.

As mentioned many of these features have been automated today.

As the network grows in complexity during the late 1970's and early 1980's the need for additional status information and automatic action will be necessary. The use of larger central processors will give some relief by apportioning more time to busy switch matrices than to the more lightly loaded ones. The reallocation of transmission facilities can also be done automatically through the use of common signal data channels. Current trends towards centralizing status and control centres will probably reverse by the 1980's as technology provides more of the automatic network control features economically in the individual central processor units.

(c) Traffic and Usage Recording Will Become Decentralized and Provide Much More Engineering Information

The network must provide accurate information regarding traffic growth and calling rates within the network as well as usage information for long distance and special service features. This aspect of the network function will shift gradually as the cost of message accounting hardware yields to technology and decreases. Present centrally located automatic message recording will change to become a part of each central processor unit with stored information being transmitted at intervals to centralized billing centres. Similarly traffic information collection will become an integral part of the individual central processor units. It can be expected that this method and associated technology will provide more sophisticated data for traffic engineering by types of service, blockage and user.

(d) The Network Will Provide Message — Usage Billing if Required

Many new services will differ significantly in information rate and call duration from the regular two-way voice service which predominates the network today. A means of billing based on measured channel usage and information rate, rather than on a rate and service average

basis, would thus be beneficial in stimulating new service offerings and uses of the network.

Most present long distance calling is billed automatically through number identification and recording equipment on a usage basis. The majority of this expensive recording equipment is centrally located in metropolitan or Toll centres. The incremental costs to extend the use of the existing equipment to allow special billing treatments on a message usage basis for all individual customers would be prohibitively expensive today.

In the future, the recording equipment for toll calls will become decentralized as the function is provided economically within the electronic stored program control local switchers. The costs for additional equipment in these new offices, to measure all local calls would be mainly associated with the costs of additional memory and processor time. Both of these costs are expected to fall during the next decade. It would thus be practicable to provide message-usage billing on a gradual basis where required and to adapt billing systems to the individual users needs as new switching systems are placed in service should such a proposal appear desirable.

(e) Network Maintenance Will Require Higher Reliability and More Automation in Network Testing

One of the most important aspects of high growth is the extent to which new technology can provide lower maintenance effort. Without improvement of equipment reliability (which is considered extremely good today) it would be virtually impossible to maintain the network in twenty years because of sheer network size and equipment densities.

Many advances in equipment system reliability will be made during this decade through the continued use of switched duplication and redundancy. The use of automatic testing will be extended from individual subsystem testing in the 1970's to total system testing during the 1980's.

Centralized maintenance centres will be introduced during the 1970's where centralized expertise can be used more efficiently with computer analysis tools during the clearing of trouble conditions. Similarly during the same time period, new testing ability brought about by new testing technology and some self maintenance capability of the switchers, will allow most routine maintenance to be handled either remotely or by a roving maintenance crew.

The second decade will see a continuation of this pattern with more and more capability of automatic diagnosis and correction being built into the central processor units. Again when needed, centralized control centres, although probably more numerous, will provide computer analysis of trouble patterns, high level technical backup and rapid trouble clearing capability.

5.1.6 The Economic Environment

To ensure the technological developments discussed in this paper which will be necessary to meet the user's requirements large amounts of capital must be attracted by the common carriers.

An appreciation of the amount of this capital can be gained by projecting the past growth of the member companies of the Telephone Association of Canada as shown in Figure 16. This shows a requirement of approximately 1.5 billion dollars in 1980 and 3.8 billion dollars in 1990, excluding depreciation.

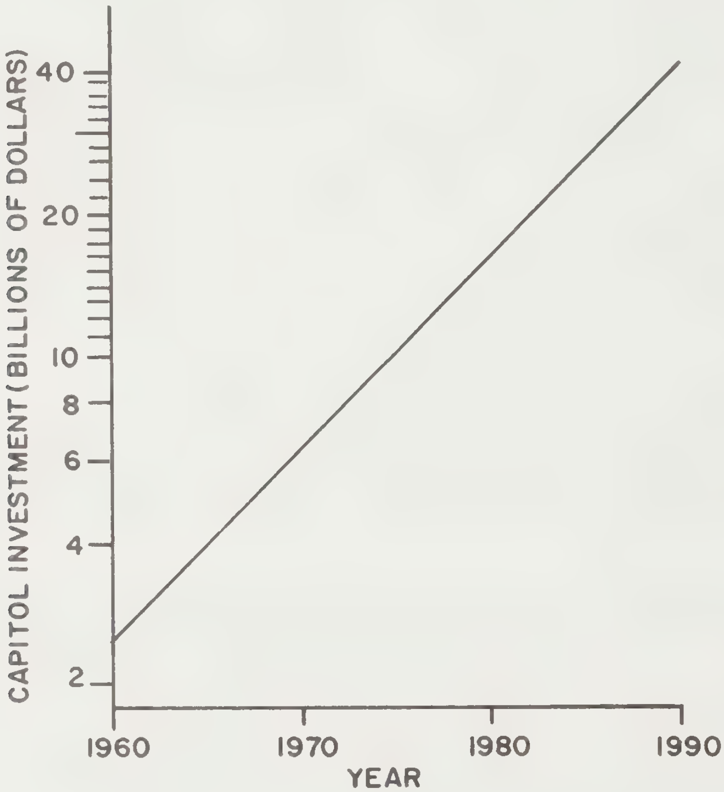

Fig. 16. Projected capital investment Telephone Association of Canada.

In order to fulfill the role assigned to the common carriers, they must be supported by realistic regulatory policy which fully recognizes the need to produce earnings that will attract these large amounts of capital.

The absence of such a policy can only result in deferral of needed capital spending, deferral of the cost and service benefits of newer technology and the proliferation of private facilities and thereby increasing total communication costs.

In essence, the future of communications depends on today's earnings.

5.2 BROADCASTING

New technological developments that are expected to have an important impact on broadcasting in the next twenty years are cable systems, home audio/visual playback systems, space satellites, and solid-state electronic devices. These new technologies are already well known, but their impact on broadcasting so far has been slight, except for the transistor.

The effect of the new technologies will be to provide a much greater diversification of program content and services, at a cost low enough and a quality high enough to generate new mass markets in Canada.

History has shown that the rate of penetration of a new technology, for example, color television, is slow and that the penetration of more than 50% of the potential market takes typically one or more decades. Therefore, it is considered unlikely that any new technology not already known will affect broadcasting in the next twenty years. That is not to say that nothing radically new will be invented, but that the probability of it being introduced commercially and substantially in this time period is small.

It is expected that the growth of the new technologies described below will be vigorous during the next decade, but that the growth will not be sufficient to change significantly the system of broadcasting stations now in operation. In the second decade, from 1980 to 1990, the penetration of the new technologies is likely to be sufficient to change the role of the broadcasting system, but not to eliminate it. Broadcasting has advantages that cannot be offered by the other technologies, for example, it can offer a service to mobile audiences. It is expected therefore that by 1990, broadcasting will have evolved to take a new position in the gamut of communications technologies, side by side with the newcomers.

5.2.1 Spectrum Usage for Broadcasting

Spectrum congestion in the AM radio band (535-1,605 kHz) will probably increase, the impetus to use the FM radio band (88 - 108 MHz), now not greatly used in Canada, for audio broadcasting.

Whereas in Canada the VHF/TV band is congested, the UHF/TV band is largely untapped. The present Canadian UHF television allocation plan provides for a maximum of seven separate additional television programs to Canadian cities. It is expected, therefore, that in the next decade much use will be made of the UHF band to provide additional program channels, for example, education and second language.

Broadcasting has been allocated a share of the band 11.7 to 12.7 GHz. Preliminary planning in Europe and North America suggests that this band will be used for space satellite broadcasting to cable systems and, perhaps, to home viewers. It is expected that some use of this band will be made in the next decade.

Proposals to use the UHF band for broadcasting from space satellites are not expected to be implemented.

5.2.2 Cable Systems

The longest path length from source to receiver in a present day cable system is 35 miles; with today's equipment this could be increased to 100 miles. There is no hardware available today to connect cable systems together over longer distances. It is expected that by 1980 facilities with adequate bandwidth (54 to 216 MHz) will be available if required for a 'national grid' of cable systems. Space satellites are expected to play an important role in any such network.

Today's TV receiver covers the VHF bands 54 - 88 MHz and 174 - 216 MHz and gives 12 channels. Receivers imported or sold since 1 July 1968 also cover the UHF band 470 - 890 MHz for a total coverage of 82 channels. The so-called "mid-band", 108 - 174 MHz, is not available to broadcasters as it is used primarily by the aeronautical and land mobile services. The FM spectrum space 88 - 108 MHz is usually used for FM radio services in cable systems. Cable system companies would like to use the entire spectrum between 54 - 216 MHz (or even 300 MHz). A new type of television receiver (a cable system receiver) would be needed to select up to a possible 27 channels throughout this bandwidth.

Presently available VHF technology can be adapted to provide a significant number of additional cable system channels in extended VHF but there are other technical problems in addition to receiver conversion. The major technical difficulties in implementing this development include the overhauling of existing cable systems to reduce radiation in and out, (to prevent interference between cable and mobile or navigation communications systems) the establishment of a suitable channelling plan and the re-equipping of the great majority of existing CATV systems with the new broadband amplifiers of adequate performance. Work on these problems is in progress.

The attenuation of UHF TV signals on present day coaxial cable systems is so great as to make UHF impractical for general distribution. Cable manufacturers are making efforts to improve cables for this purpose.

There is, normally, no solid connection between the broadcast station and the cable systems. There is, obviously, no technical difficulty in making this connection, and there is a considerable advantage in terms of technical quality.

Cable systems are a strong contestant for the consumer's dollar. At the present time 20% of TV viewing in Canada is via cable systems. It is expected that by 1980 at least 50% of TV viewing will be via cable systems.

5.2.3 Home Audio/Video Playback Devices

During the next five years, 1970-75, it is expected that playback attachments for the home television receivers will be in commercial use as follows.

The CBS/EVR system uses recordings on photographic film and is in an advanced state of development. The cost of the playback attachment will be, initially, $1,000 for black and white, and $1,400 for colour. It is expected that within the next decade a cassette for half an hour's program will cost little more than a phonograph record. EVR will probably be in commercial use in 1970.

The RCA/VPS (Selectavision) system is in an early stage of development. It uses holographic recordings on vinyl tape. Quoted prices are $600 for the playback attachment, and $2 to $3 for a half hour colour cassette. VPS is not likely to be in commercial use before 1973.

Several manufacturers are working on home videotape recorders, using magnetic tape, that are expected to cost no more than $1,000 for colour, and $500 for black and white. Unfortunately there is no compatibility between machines from different manufacturers. An advantage of the home VTR is that it can be used to record programs 'off air' for later playback. Also, it can be used to make home electronic movies with a vidicon camera. At least one of these home VTR's will be in commercial use by 1972.

The CBS and RCA systems are essentially methods of printing in large quantities audio/video programs (video records) in a suitable form for simple inexpensive home playback devices. Home VTR manufacturers are expected to offer a similar video record (pre-recorded videotape cassette), but the multiplicity of VTR types, and the higher cost of recording on video tape is likely to put this medium at a disadvantage. Video records are expected to be a substantial mass market by 1980.

The home VTR plus vidicon camera may be considered as competition for the 8 mm amateur film package. The latter is likely to be considerably cheaper and better in quality for the foreseeable future; also, it is more portable. The home VTR camera package has the advantage of immediate playback, and it is expected to have a small but significant share of the 'home movies' market in the next decade. In the 1980's the use of solid state picture sensors will reduce size and cost of the TV camera to make it more competitive with the film camera and to increase its share of the market.

5.2.4 Space Satellites

Canada's first domestic communications satellite will take its place in 1972 as part of the CBC's program distribution system. Its main advantage is complete and identical coverage for both French and English TV services to anywhere in Canada, including the Yukon and North West Territories. It is expected that all developing communities in Canada will have access to the space satellite by 1980. There is no technical reason for not distributing radio signals in a like manner: depending upon government funds and social demands this may happen at any time.

Later in the decade it is expected that satellites will be in position to transmit in the 12 GHz band (see 5.2.1 above) directly to

community cable systems and, perhaps, to augmented home receivers.

International satellites placed over the Atlantic and Pacific have been used since 1962 to connect Canada to broadcast systems in other continents. This type of intercontinental programming is growing in number of hours per year. There are several different television systems in use in broadcasting around the world; the technical quality of the exchanged television signals has been greatly improved by the recent development of an all-electronic systems converter. It is expected that these systems converters will be in widespread use by 1975 and that they will help to promote the growth of intercontinental programming between nations.

There is little likelihood of a single international television standard being adopted in the next 20 years because of the vast amounts of money tied up in existing plant and home receivers, and also because the development of a satisfactory systems converter makes unnecessary the adoption of a single television standard.

5.2.5 Home Receivers

Today's typical television receiver is still full of vacuum tubes. A recent small and slow introduction of solid state devices and integrated circuits to television receiver circuit design is likely to gather momentum and take over from vacuum tubes entirely by 1975. The improvement in reliability, stability, size, heat dissipation and, eventually, cost will be considerable. If receiver performance were to be improved,better TV band spectrum utilization could be achieved.

(a) Display Devices

Present day display devices (cathode ray tubes) are expected to show continuing significant but undramatic improvements in terms of brightness, colour rendition, stability and general picture quality. Colour display tubes with larger scanning angles are expected to be available in 1970 with consequent reduction in depth of the television cabinet.

A great deal of work has been and is being done to perfect various forms of flat television screens. So far commercial success has eluded these efforts, and it is improbable that during the next five years a radically new display device will be commercially viable. The flat display device most likely to be successful is the solid state matrix of light emitters: but this is not expected before 1980.

The use of laser beams to provide large bright two dimensional colour picture displays has been demonstrated in the laboratory. Also, lasers have been suggested for three dimensional colour television displays. There is considerable uncertainty about when these devices might be commercially available in the home, but it is not likely that they will be available before 1990. A public system of stereoscopic TV is very unlikely during this time period.

(b) Other Home Terminal Devices

Facsimile printers, e.g. the RCA Homefax, have been demonstrated to provide a one-way hard copy of print or data. The RCA system provides an electrostatic printout from information in the television vertical interval. In this case, the technology is developed, and is awaiting a demand.

A facility that is now in operation experimentally in several countries is bi-lingual television. That is, the home viewer has the choice of listening to one of two languages. There would appear to be social and political advantages in such a scheme for national events such as sports. The cost of the home receiver adaptor in one of the systems under trial, in Japan, is less than $100. There would appear to be no technological difficulties in implementing this facility at this time.

5.2.6 Solid-State Technology

The predominant factor in the growth of new services for the domestic user as described in the sections above will be the development and use of new solid-state devices. This will lead to extreme cheapness of performing electronic tasks. Radio, recorder-reproducers, TV sets, will cost a decreasing percentage of a family's income in the next two decades. The size, reliability, stability will be correspondingly more attractive to the user. Solid-state devices such as transistors, integrated circuits (IC's), are already in use; large scale integrated circuits (LSI's), are expected to be in use in 1975, solid-state display devices and pick-up sensors are expected to be in use in the early 1980's. Program origination equipment and signal distribution and diffusion equipment will take full advantage of these new devices in the same time span to improve quality, reliability, stability. In the case of program origination, high speed digital computers using advanced solid-state devices will be used increasingly to control program traffic.

5.3 MOBILE COMMUNICATIONS

5.3.1 Marine Communications

Earth Satellite Systems

There is general agreement that the application of earth satellite technology will revolutionize marine navigation position determination and marine communications. At present, the US Navy Navigational Satellite System (UNSS) with four satellites in orbit is being evaluated. Positions can be determined at time intervals of approximately 100 minutes in any weather, day or night.

The General Electric Company have recently conducted position tests via ATS-3 on VHF.

NASA is presently conducting an experiment in satellite navigation and communication aboard SS Manhattan on its second Arctic voyage using

ATS-5 in synchronous equatorial orbit as a relay from a ground station in California. The communication experiment will test the satellite's contact with the ship at high latitudes through data transmission at teletype rates. It will also test the effects of Arctic weather, ocean surfaces and signal reflection from surrounding ice. Navigation experiments will determine the capability of calculating the location and speed of the ship. This is preliminary to a system that will furnish intersecting signals from several satellites for precise position location.

Indications from the Inter-Governmental Maritime Consultative Organization (IMCO) meetings suggest that satellite development for marine communications will grow very slowly. It has, however, been pointed out that a satellite system for the exclusive use of shipping might well be justified economically. A day saved in the operation of a large ship represents a saving in the region of $10,000 and the cost of a satellite system per ship should not be large. Spectrum utilization problems will be severe. Probably some kind of inter-coast station satellite trunking would have to be used with messages spilled at high speed over satellite link.

Satellite systems will probably be of little use to small ships. On the other hand a satellite system is a superior alternative to any other long range positioning system for a survey tool in off-shore exploration and production. Rapid progress in exploiting off-shore mineral resources could have a marked influence on the development of satellite positioning and communication systems for ships and stationary platforms at sea. The accuracy required for geophysical fixes is greater than that for marine navigation but an aid to survey can, in principle, always be used for navigation.

Ground Wave and Ionospheric Propagation

A need is foreseen for ship-shore-ship communications via ground wave and ionospheric propagation for another 15 or 20 years.

Low frequency ship-shore-ship, narrow-shift radio teletype will be used in the north.

Medium frequency ($\sim$ 500 kHz) is foreseen as needed for radio teletype and manual morse.

Continued need is foreseen for coverage in the medium frequency (1,630 - 2,850 kHz) spectrum for ground wave coverage and E layer ionospheric propagation at the higher frequencies. Coast stations would be supported by ionospheric sounding transmitters. Ships would be fitted with sounding receiver systems displaying usable frequencies.

Ionospheric propagation for single sideband radiotelephone and radio teletype via HF (4,000 - 27,500 kHz) will be needed on the east and west coasts and in the north. Use will be made of ionospheric sounding transmitters at shore stations. Ship stations should carry ionospheric sounding receivers so that the optimum usable frequency can be displayed to them.

There will be expanded use in the VHF (156 to 174 MHz) band. Public service correspondence will expand particularly on the West Coast, in the Great Lakes and in the Gulf of St. Lawrence. Eventually, on the Great Lakes and on the east and west coasts (excluding Labrador) any ship within 60 miles of Canadian territory should be able to communicate via VHF. Channels will be needed for radiotelephony, radio teletype and data. All major ports will be provided with naviagation information service via radio telephone channels. The navigation information service will be extended to cover all the Great Lakes.

Other extensions foreseen include:

The necessity for ships with VHF to guard two frequencies simultaneously.

Increased communication facilities for the recreational boater.

Channels on all bands for increased teletype and data service.

Channels assigned in the VHF band for direct printing equipment.

Increased use of technological developments that improve service and reduce human operators on ships. These include selective calling, direct printing, automatic alarm, automatic access to TELEX, AQR etc.

Line-of-Sight Communications

Except for radar, the maritime industry has made little use of frequencies in the GHz range. Recent tests on ships with portable FM transceivers at 37.5 GHz, 50 milliwatts transmitter power and a self-directing receiving antenna demonstrated good inter-ship communication to 15 miles range. There is a real need for voice communications between bridges to prevent collision, for secure communications between ships of a group and for communications that cause minimum interference. It is predicted that the use of GHz frequencies in marine communications and for traffic control will develop rapidly.

Intra-Ship Communications

The success of the 450 MHz repeater on the "Manhattan" in enabling the crew to communicate with each other from all parts of the ship using 50 milliwatt portables indicates that frequencies of 450 MHz or higher are most efficient for this purpose.

Ice and Weather Maps and Service

In the 1970-75 period ice and weather map service from satellites will be available on a dedicated VHF (above 135 MHz) or low UHF channel. The dissemination of ice information and weather forecast into the Arctic via HF facsimile to support shipping must continue until service via satellite is a reality. In recent years ice information has been transmitted to ships from the reconnaissance aircraft in the 3 to 7 MHz band. Ice information transmission will be from Frobisher and Resolute. Routine weather maps will be broadcast from Edmonton and possibly Gander.

Surveillance and Radar Systems

In the 1970-75 period, area surveillance systems based on transponders will be introduced for marine traffic control — probably initially on the St. Lawrence River. This is a system that automatically registers the longitudinal position of a ship travelling the river route as it passes through narrow-beam beacons broadcasting in the 960 MHz frequency region. The river pilot carries a transceiver and the positional data will be transmitted to Quebec City at a low data rate for data processing and updating of a longitudinal display monitoring the river traffic.

Maritime radar beacon transponders will be installed in Canada's coastal waters, including the Arctic at a rate of up to 10 per year between 1970 and 1980. These transmit at X band and sweep the band 9,300 - 9,500 MHz in a two minute time period.

Harbour radar installations and associated microwave data gathering links, computers and displays will be installed. The radars would probably be concentrated at the upper end of the 9,300 to 9,500 MHz range and the microwave links in the 5,900 - 8,500 MHz range.

Power Limitations

Instructions to use "as low power as possible for transmission" are not effective. Often ship-carried equipment does not have variable power and often the operator does not bother to reduce power. In the interest of limiting interference, equipment that would automatically adjust power to the minimum necessary for good communication would be most useful. This might be done by reference to the level of the received signal.

5.3.2 Air Communications

Improvements in and extensive application of communications and associated navigation and surveillance will play a major role in meeting the problems of rapidly expanding air traffic.

Navigation Systems

The VOR-DME/TACAN ICAO Common System will probably remain the principal radio-navigation system for the next decade. More facilities will be needed in terminal areas. Frequency saturation is a problem. VOR accuracy is in urgent need of upgrading in congested areas. The most important navigation developments, however, will be in improved use of the outputs of airborne navigation equipments. This will permit computation and velocity complementation in achieving three-dimensional precision navigation and Estimated Time of Arrival (ETA) control. This can be achieved with only minor changes of the radio signals in space, although considerable expenditures will be needed for improving and expanding ground facilities.

Air Traffic Control (ATC) Systems

The predicted navigation improvements will tend to shift navigation responsibility to the cockpit and therefore reduce the communication load. ATC and separation assurance requirements, together with the general increase in traffic, will necessitate expansion of communication and also reduction in the time required to establish controller-pilot communication. It is expected that the ATC system will eventually provide a tactical, quick reaction, separation assurance function that will permit greater traffic densities and higher safety levels. Prerequisites for this are: improved surveillance; automatic reporting of altitude, velocity, rate-of-climb and perhaps position; some kind of addressable data-link. There are several technical approaches for achieving these functions, and it is not clear which will be adopted. The present surveillance system is being upgraded by the NAS Stage A and ARTS III programs, which will probably be completed about 1975. It is clear, however, that these programs will not provide adequate separation assurance or sufficiently small delay times for the predicted further future traffic densities.

It is highly likely that new developments will be effected to meet these separation assurance needs. One possibility is the program outlined by the US Air Traffic Control Advisory Committee (December 1969). This envisages the use of electronically scanned addressable surveillance signals and improved transponders which would reply with all needed kinematic data ("Super Beacon"). The data thus derived would be used for greatly improved scheduling functions and separation assurance in the 1975-1980 era.

Integrated Navigation and Air Traffic Control Systems

Various schemes have also been proposed that use satellites as relay and ranging points for navigation, surveillance and communication. For example, the USAF has proposed a satellite navigation system (621B) requiring a constellation of four or five satellites in a "Y" or "X" configuration orbited over the North American continent. This would be one-third of a global system. To utilize the system, aircraft would have to carry a high-quality quartz crystal frequency stabilized oscillator and a computer, or a transponder for relay of signals to a ground station. Such a system would apply to both military and general aviation users. This system could also be built up to a unified communications, navigation and identification system (U-CNI), which would replace all present radio equipment with one wideband transceiver operating at UHF or higher frequencies.

The wideband digital signal would enable multiplexing of several functions onto one transmitter and permit signals transmitted from many sources to occupy simultaneously the same portion of the radio spectrum (multiple access). These satellite schemes appear to require much development work and probably could not be in operation before 1980-1985.

There is some possibility that separation assurance will also be improved by use of air-to-air techniques along the lines of the ARINC

Air Transport Collision Avoidance System (ARINC Paper 587). This system uses synchronized oscillators and transmissions in the 1592.5 to 1622.5 MHz band to derive range, range rate, and altitude difference and rate to detect and resolve dangerous situations.

Instrument Landing Systems

The improvements in navigation, surveillance, communication and control, will also be used to effect better sequencing and scheduling in the terminal area, and therefore improve runway capacity. From the radio signal viewpoint, the greatest change (in addition to the surveillance and data link functions already cited) will be the introduction of scanning-beam microwave Instrument Landing Systems (ILS) to replace the present VHF ILS. In the US, Special Committee 117 of the Radio Technical Commission for Aeronautics (RTCA) recently chose the scanning-beam technique as the most promising new guidance system. The system will probably operate on C or Ku band frequencies. RTCA has formed several teams to further develop the scheme, which is predicted to be available by 1980.

Auxiliary Air-Ground Communications

In addition to the communication required for ATC, there is a growing need to communicate a wide range of technical and operational information for the more efficient operation of passenger and heavy general aviation aircraft. Rapid growth of VHF data link for this purpose is anticipated.

Another factor that will become apparent in the next ten years, is the increasing demand for private citizen communication on both private and commercial aircraft. A mobile telephone system, utilizing a wideband, multiple access radio link would fulfill this need.

Most other technological changes in air mobile telecommunications equipment are expected to be in the direction of improved unit reliability, system integrity and reduced spectrum occupancy.

Auxiliary Services Communications

Data Switching Systems are being increasingly used in passenger reservation and weather reporting systems. The main system implications are in the area of increased demands upon the communications network for data transfer capacity.

5.3.3 Ground Mobile Communications

(a) Vehicle Identification

Vehicle identification by automatic transmission of a coded signal at the beginning of a message, will be provided in future systems to conserve communications time, to identify the source of an alarm signal without alerting criminals and for record or control purposes when vehicle data is stored at the central station. It will also be used for automatic acknowledgement when polling is carried out from a central point.

The problem of supplying such a system is not technically complex. However, the limiting factor has been one of cost. This cost factor will be materially reduced in the early 70's with the application of integrated circuits to mobile devices and the introduction of digital transmission.

(b) Vehicle Status Monitoring

The efficient dispatching of mobile fleets, requires up to the minute knowledge of the status of each unit within the fleet. Is the unit in operation? Is the driver in or out of the vehicle? Is the unit on an assignment? When will the vehicle be available for re-assignment? Here again the basic technology is available, however a great deal of up-dating of equipment and systems will be required to capitalize on its advantages. Status monitoring will probably only be one facet of a vehicle location, identification and status monitoring system. The adoption of computerized systems for these purposes will see wide-spread application in the early 1970's.

(c) Vehicle Location

The general problem of vehicle location is one of determining position in a two-dimensional environment and communicating this position to a reference point. It is desirable to accomplish this automatically with no human intervention required. The location system must have a referencing system and some means of measuring or otherwise determining coordinates with respect to the reference. In addition to determining position and recording this at a central point (or points, depending on operational requirements) the system must identify the individual vehicle involved.

There are a number of means of specifying positions in a plane. All are dependent upon knowledge of appropriate angles or distances which must be measured. Six possible reference systems are described in the Appendix and are as listed below.

1. Cartesian Coordinates (x, y, or rectangular coordinates)
2. Polar coordinates
3. Triangulation
4. Measurement of three distances
5. Measurement of two differential differences
6. Measurement of two differential angles.

Described also in Appendix D are location determining techniques of three basic types. These are as follows:

1. Direct measurements
2. Coded environment
3. Derivative measurement

Possible system approaches for the solution of the provision of vehicle location information are

1. A radar transponder system
2. A hyperbolic system
3. An electronic signpost system
4. A derivative (compass-speedometer) system
5. A system making use of the existing radio signals.

Certain designs and various versions of these systems (which are described in Appendix D) have been devised. While their practicality may not have been proved out in the field, the need exists. Proof of performance will be ascertained during the early 1970's and systems should be in general use in the latter half of the decade.

(d) Record Form Communications

There are many operating conditions under which it is desirable to have a lasting record of the message being transmitted. Examples of these requirements are the transmission of license numbers to police vehicles, the transmission of clearance orders to works crews in utility maintenance on construction and the transmission of instructions to any mobile operator who may be away from his vehicle from time to time. There are many times when a record of messages is desirable at the control centre.

In a previous section there has been mention of a page printer which will meet all mobile record form communication requirements. It is also adaptable for facsimile transmission.

Record form communications in addition to providing a hard copy record, have the further advantage of a certain amount of security due to the use of digital transmission means.

Developments over the next few years will be aimed at expanding hardware availability, reliability and reducing cost.

(e) Mobile Visual Systems

There are many needs for visual display systems in vehicles connected with law enforcement, riot control, traffic control, etc. They would also be a valuable adjunct to urban and rural fire fighting forces.

The technology necessary for the provision of such systems is readily available and the needs are there. Implementation of development awaits policy decision and authorization by Department of Communications, for the use of such systems.

(f) Safety on the Highways and Waterways

Various public safety agencies, primarily fire departments and police departments, have expressed an interest in systems to enable a citizen in distress to call for assistance. The need may be for medical aid, disabled vehicle assistance, assistance in case of man-made or natural disaster, or protection purposes.

In populated areas the use of existing wire networks can often fulfill the need, however, a greater problem exists in rural areas.

(i) Portable Radios for Emergency Aid

It would be feasible to equip personnel who will be in out-of-the-way areas such as campers, construction workers, etc., with relatively low-priced special portable radios for use in case of emergency. The owners of such resue radios could be registered or licensed under similar regulations as present in effect for automobiles or guns. This would provide a control for false alarms or malicious transmissions when combined with a system of individual coding of units to enable the source of any transmission to be identified by its transmitted code.

Such an emergency calling system may require strategically placed satellite receivers to extend the effective range.

(ii) Detection of Off-the-Pavement (Disabled) Vehicles

The great increase in highway traffic makes it increasingly important to deal with disabled vehicles as, even if they are off the highway, they present a considerable hazard.

A number of interim solutions have been proposed and these are explained in detail in Appendix D.

The ultimate solution would be a system which would require no action on the part of the vehicle operator. Such a system would signal a central station automatically when the vehicle is driven off the travelled portion of the highway. Such a system will probably only become economically feasible when included as part of the "Ultimate Electronic Highway".

The "Electronic Highway" will require a communications network for guidance, to maintain the vehicle in its lane and for maintaining safety and distances between vehicles. The detection and location of disabled vehicles would then be a reasonable adjunct to this communication network.

The "Ultimate Electronic Highway" is likely to evolve over an extended period of time. Its implementation will be costly and protracted due to the thousands of miles of expressways and millions of vehicles which will have to be equipped. Forerunners are likely to be systems requiring driver action. Three such systems are being evaluated in the United States on a pilot basis.

These are:

1. a two-way system employing pole-mounted, solar-powered, vandal protected installations located at strategic positions along the highways. It is anticipated that such a system could be used to coordinate emergency services, traffic sign activation and traffic density data.

2. a wired telephone-type system which links roadside stations to a central aid station.

3. A system using a resistance measuring technique for computing distance to the signalling point. It does not require expensive components such as telephones or radios, however the necessity of a buried cable for vandalism protection results in a high installation cost per mile.

   With the "Ultimate Electronic Highway" in view a cable system as required for this application might be used to conduct power to the electronic equipment required in the ultimate system.

   A system using distress transmitters mounted in each vehicle, has problems associated with cost, inadvertent or malicious false calls,and multiplicity of wayside receivers. These problems at the moment would appear to mitigate against its implementation.

(g) Security and Privacy

The need for security and privacy is most evident in mobile systems dedicated to law enforcement needs. Systems devoted to other applications have varying needs in this regard. Many devices have been designed and vary widely in the degree of security which they provide. They range from simple speech privacy equipment to complex data processing apparatus which protects against decoding of information for periods measured in years. Cost of such equipment varies greatly dependent upon the degree of security provided. The simpler type of speech privacy device is already available at moderate price. More advanced devices for either speech or other types of information protection, can be provided within a reasonably short time. The technology is available, but the development of equipment awaits the resolution of operational problems and definition of methods of use by the user.

(h) Personal Communications

In recent years, the trend of communications for the man in motion has been for light weight portable radios in addition to the more conventional vehicular powered set. Examples are the personal portables used by airport personnel, by the policeman on his beat, and industrial personnel in pursuit of their activities within manufacturing plants,oil refineries, etc.

New technology has created improvements in reliability, performance, reduction in size and weight. Further reduction in weight, size, increased battery life, and greater power output, are foreseen which will better meet the existing needs.

Within the next five years, helmet radios which do not obstruct the user, will be available with power output equal to today's hand-held portable unit. These will be made possible by the use of integrated circuits on a medium or large scale integration, combined with hybrid microelectronics. A breakthrough in battery technology; which seems highly likely, also will enable the production of smaller units.

Integrated circuits and micro-miniature techniques which make the helmet radio possible will also improve the feasibility of a wrist receiver. It is anticipated that a simple version of a wrist receiver will become feasible within the next five to ten years. A complete two-way unit, including a low power transmitter is several more years distant.

(i) Mobile and Portable Alarm, Signalling and Controlling

Multi-function encoders enable a variety of conditions to be monitored, for example, building entry, smoke or fire occurrence, heating system condition, etc. Changes of status indicated may activate a radio-transmitter and relay the information to a centrally located monitoring point.

In the same manner that alarms may be transmitted by radio, control signals may be conveyed to actuate devices in remote locations. Radio control of cranes, for example, is an established application. Extension of this type of system to the control of locomotives, marine vessels and land-mobile vehicles is likely for special applications. Greater use of radio signals is anticipated for the control of such things as valves in oil fields, start-off of standby generators, etc.

(j) Emergency Medical Monitoring

In Electronics News, page 44, September 9, 1968, a new technique in medical electronics and communications was publicized. An ambulance service in Los Angeles had tested a modification of NASA's electrode body function monitor. The system transmits the heartbeats of a cardiac patient over the ambulance radio to the ambulance service dispatch office where the information is relayed by a special telephone line to an EKG recorder at the hospital. Thus a doctor can examine the electrocardiogram and make preparations for the reception and care of the patient while the patient is en route to the hospital via ambulance.

Electrical signals from the patient's heart are picked up by "dry-spray" electrodes attached to the chest. The heartbeat signal is modified by an amplifier-FM modulator. The FM tone is played through a smaller speaker into the microphone of the ambulance's two-way radio. An FM/FM transmitter wave results.

With the present system, voice and heartbeat information cannot be carried simultaneously. The availability of multi-channel FM radios should make it possible eventually to send information on other physiological functions, such as blood pressure, pulse wave velocity, respiratory volume, skin temperature, and many others. Some of these could be sent simultaneously over a single radio frequency by using data multiplex techniques.

The systems described here are feasible now, will save lives, and be in widespread use in five years. A secure channel will be required ultimately for this service.

(k) Highway Routing and Guidance System

Automatic automobile driving has received considerable attention in the technical literature. With the prospect for improving highway safety and affecting the well being of so many people, this is understandably so. The problem is extremely complex, however, and even our advanced technology at this time yields only a partial solution.

Essentially three problems must be solved. The first, lateral control or steering is relatively easy as a radiating cable in the roadway with appropriate sensors in the vehicle would seem to be within present-day technology. Longitudinal control (speed, acceleration, braking) is more difficult and various means have been proposed, some depending upon relations with a lead vehicle. A system using laser frequencies has been proposed to control automatically the distance between the vehicle and the one ahead. The third problem is combining the two systems and providing the necessary self-test and backup sub-systems.

The automatic automobile driving system is unlikely to use spectrum which is competitive to land-mobile users, however, the advent of these systems, probably in the late 80's will almost certainly generate additional communications requirements for the vehicle since, relieved of his driving responsibilities, the driver may well involve himself in other tasks requiring communications.

(l) Air and Water Pollution Monitoring and Policing

In air pollution control, mobile radio communications has offered the only practical means of contacting pollution inspectors and getting them to the scene of a violation within a matter of minutes. This is critical, because if the inspector arrives after the violation has ceased, there is no evidence and the violator cannot be prosecuted.

Oil pollution of the Great Lakes by shipping has recently come under surveillance by the Government and in this case, an aircraft, equipped with mobile radio on the marine channels, can contact the ships' captain and coast guard stations relative to the violation. Aerial inspection, in fact, is the most effective way of combatting air pollution, both from the standpoint of observing the violation and photographing it. It also enables the inspector to reach the scene quickly while the evidence is fresh.

With increasing befouling of our environment, we need the most effective means of control. Frequencies for this service must have priorities equivalent to those for public safety.

Automatic monitoring of the environment can also be effected using radio channels. Sensors at strategic locations will detect pollution levels and automatically report values when interrogated by a central station or when values exceed a certain present maximum. Such a system is similar to those presently in use to monitor meteorlogical functions.

5.4 INFORMATION PROCESSING NETWORKS

As we look into the future through our crystal ball, clouded by the observations in Section 2.4, the only obvious conclusion is that there is no obvious conclusion. The computational capacity in the country will surely grow by a few orders of magnitude in the next 20 years, but where will this growth occur?

The number of giant computers, including those with large storage systems but small CPU's, will increase but perhaps by less than an order of magnitude. A relatively small number will be necessary to meet the country's needs for reference material as previously discussed. A few large computer complexes will find a place in government service. Several more moderately large systems will fill the needs of those people and businesses with very little or infrequent use for computer services. A simple terminal with optional connection through the local telephone company will adequately meet these requirements.

The biggest increase will be in the number of small systems. The following quotation from the March 2nd, 1970 issue of Electronic News gives one view of this, although the computer industry in this country is not in agreement with the figures quoted. They do not all share the optimism of Honeywell's Mr. Bothwell that the advent of the minicomputer will "doom large main frames".

"Minicomputers — armed with phenomenal advances in technology — will doom large main frames except for systems requiring large data bases.

"That's what speakers told members of the American Management Association last week at their 17th annual EDP conference in a session of 'The Minicomputer Invasion'.

"Advocates of the small giants — with their ever-expanding capabilities — contended that their use with low-cost peripherals will reduce line charges and improve reliability, that pyramiding minicomputers will bring fantastic reductions in programming costs for large systems, and that minicomputers will take over such specializing functions as communications switching.

"T. Paul Bothwell, vice-president and general manager, Computer Control division, Honewell, Inc., said that small businessmen will have to turn to dedicated minicomputers to stay competitive.

"He forecast that by 1975, six of every 10 computers will be mini-computers — 80,000 of a total of 130,000. There are only 10,000 today."

There are only two exceptions likely to become important. The value of a computer utility as opposed to individual systems will be primarily not in the hardware components but in software availability and operator convenience. These can be very important considerations in some applications. The other situation involves an in-between size of system. There is a trend of industry and business going to larger-size complexes. These organizations will be able to afford their own centralized computer system in connection with their head office operations, but they may still need the computer utility for performing technical and financial chores on an 'as and when required' basis for their various local departments. They may well find this the best economic approach. The centralized computer system will introduce a real need for satisfactory and cheap telecommunications facilities between scattered plant locations of the same company. Common carrier lines are the obvious choice, if they are available, and if they meet the desired specifications. The computer will become an integrated part of the individual business, handling such diverse tasks as inventory control, payroll, billing, management decisions, and process control. Except for some applications along these lines the medium-size computer may very well become obsolescent.

6. CONCLUSIONS

6.1 THE ENVIRONMENT

The development of communications systems in Canada will be shaped by the following main requirements:

(a) The demand for a variety of narrow and broadband services, combined with pressure to have equal services available everywhere.

(b) In mass communications, the increasing requirement for a wide variety of programs to be available to individuals on demand as well as on a scheduled basis.

(c) Rapidly growing mobility, with the resulting traffic control problems and the requirement for continuous availability of communications to people on the move.

The main unknown lies in the nature of demographic developments. The cost and the nature of the optimum communication systems will depend on whether the present trend to urbanization will continue, or will be reversed. Improved communications can help to make the reversal possible (at a cost), but the issue will be decided on non-technical grounds and is thus not a subject of our predictions. It must be stressed, however, that an early prediction and policy development in this field is of

paramount importance to the economic and satisfactory growth of communications in Canada.

If the trend towards urbanization continues, the suburban spread alone will necessitate that much of the office work and of learning be accomplished at home some ten years from now.

6.2 BASIC TECHNOLOGY

The time between the discovery of a basic technology or device and its incorporation in production equipment with significant impact on the life of the general public has been about 20 years in the past. No major reduction is expected. The basic technologies that may be used to provide the facilities foreseen in the environment for the next two decades are thus already known, but implementation must await significant cost reductions, either by further technical development, improved methods of fabrication or through the development of large markets.

Continued R&D on the control of microscopic, molecular and atomic processes will result in new devices with a multiplicity of functions and with high operating speeds that can be fabricated quickly and cheaply. Large scale integration (LSI) will result in a reduction of cost and size of sub-units by a factor of about 30 times in the latter half of this decade. Hence, equipment will be manufactured which will perform complex functions with less control and maintenance by human operators than was required by simpler equipment in the past. All active communications equipment, except that with high output power, will be made from solid state components.

Large memories are vital to communications technology and to all aspects of data handling and display. Ferrite core memories will have a dominant position until at least 1980, when they are likely to be overtaken by integrated circuit (I.C.) semi-conductor memories and by magnetic bubble and holographic memories for bulk storage. Cost will decrease by several orders of magnitude in the 20 year period.

1.5¢ — 8¢	per bit for ferrite core now
0.1¢ — 0.5¢	per bit for I.C. memories by 1980
0.001¢	per bit possible for high density memories in late 1980's.

The storage density in serial access-type, bulk storage devices will increase from about 1 Mbit/sq. inch to possibly 100 Mbit/sq. inch over 20 years.

The evolving technology will provide a wide proliferation of input-output devices and various transmission bandwidths. These will match the need of the user and will allow a considerable number of new visual services which will complement the audio services.

Within the home, all new receivers will be solid state by 1975. Cathode ray tubes will begin to be displaced by solid-state or equivalent displays by 1980.

Home video recorders and/or reproducers will become economically compatible with other electronic equipment for domestic use.

6.3 TRANSMISSION TECHNOLOGY

The Canadian environment will require the use of a combination of terrestrial microwave, guided facilities and satellite radio to provide economic long and short haul transmission. Satellites will play an important role in providing communications to the north and variable trunking on an east-west basis coincident with the peak traffic caused by the time zones*. Sub infra-red links may provide an economic multichannel facility for TV transmission over short distances to complement cable. The high growth rates for transmission facilities (up to 22% per year on some routes) will make much larger cross-sectional capacities economic during the next two decades, due to economies of scale.

PCM Coaxial Cable	by 1975	16,000 to	20,000 circuits
Digital Radio Links	by 1980		32,000 circuits
Waveguide Facilities	by 1985	100,000 to	200,000 circuits
Laser Fibre Optic Links	by 1990	over	200,000 circuits

The progressive introduction of these facilities will continue the transmission cost improvement that is averaging approximately 6% per year for terrestrial facilities.

Satellite communications are capable of providing long distance communication links between base stations; communications between base stations and small terminals within a large geographic area; and navigation facilities to ships, aircraft and land vehicles. The first type is operational, the second is planned for India in 1972, the third is currently evolving.

Use of Large Scale Integration for electronic circuits in applications such as digital filters will allow a substantial cost reduction in Frequency Division Multiplex type carrier equipment in the period 1975-80. Beyond 1980, cost reductions in digital Time Division Multiplex equipment will offer even greater benefits. Maintainability and performance problems associated with analogue circuitry will reduce new applications of Frequency Division Multiplex after 1980. The full impact of Large Scale Integration of circuits is expected in the late 70's and e early 1980's.

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*See also 6.3, para. 2; and 6.6, paras. 3 and 4.

The economy of large cross-sectional capacity in transmission facilities and the economy of shared use, should permit large carrier organizations to offer the most economic medium for the growing new services.

The use of digital code modulation radio systems can provide much more efficient use of the frequency spectrum on a geographical re-use basis than existing FDM-FM systems, if proper frequency assignments are provided.

Distribution facilities to individual homes and businesses in the future will utilize more electronics, for broader bandwidth and improved performance and higher utilization factor. An economic combination of paired and coaxial systems will be used. The portion of the distribution system working in the analogue mode will consist of shorter, higher quality links.

Direct reception of broadcast transmissions will gradually disappear in urban and dense suburban environment, except for mobile users. This could permit a major readjustment of frequency allocations to provide multichannel broadcast television coverage for rural areas.

6.4 SWITCHING TECHNOLOGY

Future switching systems will all be common control and mainly all electronic stored program control. Such systems will easily handle the complex features required for voice, data, video program and voice program switching, using time and space division. Existing analogue space division switching will be complemented with time and space division PCM switching starting in the late 1970's or early 1980's.

The actual switch matrices will gradually be diffused throughout the network rather than concentrated, making the distribution links shorter and higher quality. The network will evolve with larger central processors serving many matrices. These processors in turn will be tied together with common data signal channels to form a true "common control network" rather than the existing "progressive network".

6.5 DIGITAL TECHNOLOGY

The evolving carrier network will be composed mainly of digital sub-systems, which can offer the complete range of digital and analogue capability required by any user on a switched network basis. As large data banks will be accessed by many people, provision of communications for data processors will hasten the transition to digital transmission.

Man's access to computers is now limited by the mechanical input devices. Document readers and voice recognition equipment will become common interface units during the late 70's, improving user freedom of access and reducing the necessary operating skill.

Electronic visual displays — analogue or alphanumeric — will become increasingly important during the next few years.

Noisy mechanical impact printers will be replaced rapidly by small silent equipment during the early 1970's.

Both large and small computers will increase in numbers and low cost small computers (adding machine size) will be mass produced. Increases of 10-100 times per decade in processing speed of large computers can be foreseen; hence, costs per function will decrease dramatically.

The minicomputers, in mass application at user locations, will act as concentrators for interaction with large remote computers or memory banks, where additional processing ability or centalized storage may be required. The result of this, for the majority of users of remote computers, will be shorter holding time and lower channel capacity requirements than those predicted in the past.

6.6 SYSTEM DEVELOPMENT

The growing sophistication of subsystems puts more emphasis on overall network optimization, but allows many more economic trade-offs than in the past,permitting greater efficiency of multi-purpose networks.

Automated operation of the carrier network will be the largest factor in system viability. Customers' assistance services must be as fully automated as is technically possible, to allow for the expected growth in the next decade. The way of the future will be to have all the functions that can be accomplished by machines, performed by machines.

A community distribution system for entertainment and education will require both audio and video capability, with pickup of national programs being provided through space satellite relay. Cable systems would supply service to high density areas, with local broadcast transmitters providing service to low density areas and to mobile users.

Satellite broadcasting directly to small community antenna systems may be used before the end of the decade, direct-to-home service possibly in the mid-eighties. This will help to equalize the availability of mass communications anywhere in Canada, but the number of channels thus provided to any one location will be limited, by high costs, to well below the capacity of the terrestrial cable systems in urban environment.

In high density areas, multichannel distribution systems will also provide a multiplicity of other services, mostly of two-way or interactive nature.

The requirement for on-demand visual services will be met partially by home and local video libraries and partially by the development of switched video systems corresponding to the present telephone systems, but with connection being made to stored information.

In low-density areas, the requirement for greater choice of programs and freedom from scheduling will be met by new developments in broadcasting in connection with home video storage devices and narrow-band request (feed-back) channels.

Radio telephones, advanced form of pocket paging systems, various terminal devices and improved mobile radio services will provide the user of the switched telephone network with greater mobility.

The growth of mobile communications will be limited by the availability of spectrum. Reassignment of bands now dedicated to other services may be necessary. Scan hunting for free channels will be introduced during the 1970's. For additional growth capability, band compression techniques, such as vocoders and their visual equivalents, will be economical during the 1980's.

The rapidly growing air and marine traffic may continue to pose serious traffic control problems, but the solutions will not be limited by the technology of communications. New and more sophisticated air navigation, recording and control systems are being, and will be, introduced, which will greatly expand the needs for transfer of many types of intelligence, perhaps leading to a unified communication, navigation and identification system.

The number of overland vehicles in use for recreation and other purposes in the wilderness areas of Canada, particularly in winter, is likely to grow rapidly. The vehicles will range far from settled areas. There will be a need for very economical mobile communications and navigation aids for these vehicles. If the scale of production is great enough technology should be able to supply the need but there will be problems of spectrum crowding.

APPENDIX A

Telecommission Study 4(a)

APPROVED TERMS OF REFERENCE

CONTENTS

General

It is the purpose of this study to describe and assess the nature and possible impact of future developments in the area of communications technology. It accordingly permeates and forms the basis for the work of all of the other Telecommission teams; for the Telecommission itself owes its existence entirely to the explosive rate of change in communications technology. Consequently, a proper understanding of the ways in which this technology may evolve is an essential prerequisite to meaningful deliberation in each functional area.

Scope of Study

Prophecy at best is a hazardous and inexact pursuit and this is particularly true when the subject matter is as broad and many-faceted as communications. All too often the critical spark that ignites a revolutionary change is some obscure piece of work in an area that is regarded as trivial at the time predictions are being made. Likewise, the sudden insights or flashes of inspiration that lead to major new inventions, are intrinsically unpredictable. The sheer size of the communications field creates another problem, and it would be impossible for the study-team to cover in depth all the technical developments that are currently appearing on the horizon. The study consequently will confine itself to providing a general summary of certain critical areas in which change is likely to have the greatest impact upon our society. The identification of these areas should, therefore, be a major preoccupation of the team in the early phases of its work.

As a start, the work of the teams will be channelled along three principal axes, each of which addresses a particular range of questions. These are:

1. *What* will be communicated?

2. *How* will this material be communicated, transmitted, processed, etc.?

3. *Who* will use the services, i.e., new developments?

The *How* dimension is concerned with such factors as:

Storage
Transmission, i.e. tropo, cable, satellite, etc.
Switching, both devices and techniques
Terminals
Control
Processing and modulation, etc.

Under the *What* category the team will be concerned with the four basic types of service. These are:

Voice
Picture
Writing
Data.

The third or *Who* dimension is concerned with the users of the different services and here three basic categories have been identified:

Domestic
Institutional
Processor.

Time Span of Interest

The team will confine its prognostications to the period between now and 1990 and, within this 20 year span, will consider four basic intervals:

1970 through 1974
1975 through 1979
1980 through 1984
1985 through 1990.

APPENDIX B

BASIC TECHNOLOGY

These studies were provided by specialist Study Groups comprised of laboratory staff drawn principally from:

Northern Electric Research & Development Laboratories,

National Research Council Radio & Electrical Engineering Division,

Communications Research Centre.

The Defence Research Establishment Ottawa staff and members of the DRB Power Sources Committee contributed in a major way to the Power Sources Technology Study.

CONTENTS

1. MEMORY TECHNOLOGY

Introduction

In this brief report no attempt has been made to make a detailed comparison of present technologies or a forecast based on specific attributes of a particular technology. There can be as many results from comparisons of two systems as there are pairs of systems. The opinions given are based on the demonstrated worth of operational devices today and the most probable trends in the use of the available technologies during the next 20 years. Account has been taken of the market conditions in which any memory system must develop and become "popular".

Technologies

The present situation for major memory systems is one of a well established ferrite core technology maintaining overall superiority over other technologies by continuous but not revolutionary improvement.

Magnetic memory systems such as plated wires which have a limited bit density and thin films with fairly stringent production tolerances are being exploited to a limited extent only, although one Japanese manufacturer has recently shown confidence in plated wires. As far as their present characteristics allow a projection into the future, it is not expected that either magnetic films or plated wires will take a very significant or prolonged share of the market. In the field of semiconductors the bipolar and MOS memories appear to be gaining strength, such devices having the backing of the allied technology developed for semiconductors not specifically intended for information storage.

For the period under discussion it is felt that ferrite cores with their developments will hold the leading position for at least ten years. Core sizes can be reduced, automation for array assembly can be improved and competition from other technologies will probably stimulate rather than depress efforts to maintain the use of cores. There is the possibility for promising combinations of ferrite material with a continuous sheet of magnetic film in the "waffle iron" type of arrangement but they do not represent an exceptionally large improvement in magnetic systems.

For another technology to replace cores within ten years it must be developed quickly, shown to be more reliable and cheaper and with improved characteristics for speed of operation, power consumption and overall size. The most serious contender is thought to be the semiconductor memories which will show considerable expansion during the next few years. The MOS device is expected to take a position in main frame memories with the faster bipolars being used for small faster systems such as buffer memories.

During the second ten year period there will probably arise a significantly increased need for a memory with greatly improved storage density. In the past, initial promise was held for cryoelectric memories

but their development has been disappointing. The proposed usefulness of "glassy" amorphous films has not yet been proven during the past few years of study. The holographic memory can provide large storage facilities with theoretical bit spacing of the order of light wavelengths, however on a less microscopic scale, the new "bubble" memory may be a more easily realized system with holography waiting for a more distant future.

Memories and Communication

In general, the characteristics of the memories which will be available during the next 20 years are unlikely to have any limiting effect upon the development of communications.

There is the distinct possibility that the peripheral systems providing access to the memory through input-output devices will be the determining factor as far as the speed of operation is concerned and could therefore be the controlling influence in the incorporation of memories of any technology into communications systems.

The reduction in the size of computers resulting partly from memories becoming smaller will allow their increased use in for example, aircraft and satellites, where space and weight are at a premium. The wing tip space for instance, could be used for packing electronics for control and monitoring of aircraft systems in connection with data links to and from ground stations thus leaving the fuselage clear for more bulky equipment.

The methods of production for any given workable memory are reflected to a large degree by the reliability of the complete assembly. As one link in a chain, the memory must have a considerably greater reliability than that required for the whole system if the need for duplicate equipment is to be avoided. The examples of aircraft and satellites quoted above are instances in which reliability can be a very important factor.

The memory will undoubtedly be incorporated into many systems for communication purposes on a very large and increasing scale. However, the present steady trends towards cheaper, smaller size and modest increase in speed are considered to be sufficient to allow the development of any system such as time sharing in telecommunications and data links that are likely to be operational within the time period under consideration.

Cost Projections

Useful cost data for comparisons and projections are difficult because they vary with memory size, speed, power dissipation, present day usage of different types of technology etc. Future computers will be structured to use optimum combinations of memory types. Also, I.C. memories have broad application for delay lines, displays, etc.

At present, ferrite core memory costs about 1.5 to 8 cents a bit. MOS serial and read-write about 10¢ a bit. MOS read-only about 1 to 5 cents a bit. Bipolar IC memories are used for fast applications and presently cost more (typically 50 cents a bit). Projections of from 0.5 to 0.1 cent a bit have been made for IC memories.

Bubble memory, based on the recently announced magnetic bubble technique, would appear to be a slow access, high bit density, low dissipation memory that could replace disc files as intermediate storage devices. Bubble memory coded data files have been foreseen as holding 15 million coded bits of information while occupying one or two cubic inches and using only 0.040 watts of power. Cost projections of 0.001 cent a bit have been optimistically made.

2. SEMICONDUCTOR COMPONENT TECHNOLOGY

Introduction

The evolution of the semiconductor industry has, at times, appeared more like a revolution because of the dynamism of the industry. A succession of important process and technological inventions has led to an extremely rapid but relatively orderly development of the field. A strong demand from the computer marketplace has also forced attention to that particular aspect, and in fact has set the pace for most of the present developments. The large number of computer oriented function blocks has,as a spin off,produced devices and circuits suitable for linear applications. The common availability of digital circuits seems destined to play a very important part in the communication field where complex digital processing techniques are now practical.

In attempting to predict the direction, or type of semiconductor device technology, two time intervals must be kept in mind:

(1) From device or process invention to significant market exploitation has taken typically three to five years.

(2) From device or process invention to device maturity as reflected by the bottoming of the price per device curves has taken about 10 years for both germanium and silicon transistors with every indication that it will be about the same for monolithic integrated circuits.

Thus it appears reasonable to expect that devices being invented now will reach market maturity in the early 1980's. The above does not mean that the life span of a device is only about 10 years because the period of maturity may last for many years.

With semiconductor devices, maturity has also meant attainment of high reliability. The reliability of devices and circuits made today, where extreme care in quality control was exercised during fabrication, enabled man to journey to the moon and safely return. The same degree of reliability should be relatively commonplace in the 80's.

Future Potential of Existing Device Technologies

Our present technology is based on elementary (one element) and compound single crystal semiconductors. The former materials were explored first and are best understood. To date they have been the backbone of the transistor and diode industry. The latter materials form the basis of an emerging industry and indicate much promise of useful devices for the microwave frequency region.

Germanium: Although germanium devices have been largely superseded by silicon, their dollar sales volume in 1969 was about 40% of the peak reached in 1961. Production of germanium devices is highly automated and they will continue, through the 70's, to be used in large quantities in inexpensive consumer (home entertainment) type applications.

Because carrier mobility figures in germanium exceed those in silicon, research into the possibility of producing microwave germanium transistors has proceeded sporadically and may continue for some time. The rather low temperature tolerance is its major deficiency.

Silicon: Silicon is the most widely used semiconductor device material. The development of oxide masking in the mid 1950's not only permitted the manufacture of inexpensive and reliable transistors and diodes but led to the subsequent development of both bipolar and MOS integrated circuits.

Although silicon transistor dollar sales volume has been nearly constant since 1966, the average price per device is still decreasing somewhat and at present is on par with germanium at just under 50 cents.

The integrated circuit sales are increasing from year to year in almost a straight line. The average price per package continues to decrease and by the late 70's is expected to be under $1.00 per package. The multi-layer metallization, cooling, testing and packaging problems associated with medium and large scale integration (over 100 gates per package) are currently being worked on, and maturity of this avenue can be expected in the late 70's. We expect that silicon will continue to be the primary vehicle for integrated circuits throughout the next two decades.

With the present understanding of device physics, conventional discrete silicon transistors cannot be expected to yield much beyond three to four watts at 5 GHz and a few milliwatts at 20 GHz. Some increase in these powers may be realized by parallelling a number of discrete transistor chips.

The market for semiconductor memories is currently undergoing rapid expansion. Projected prices are 1/10 cent per bit in large scale arrays of upwards of 1,000 bits.

Compound Semiconductors

Two features of compound semiconductors that offer exciting possibilities are:

(1) The energy band gap can be engineered to suit the job requirements.

(2) The energy-momentum interchange mechanism, causing formation of travelling field domains, gives us devices with new properties, e.g., Gunn and LSA devices.

The physics of compound semiconductors is more complex than for the single element materials and this fact has been reflected in the relatively slow development of successful devices. The next two decades however should witness the emergence of a mature technology in compound semiconductors.

Inexpensive light emitters for use in displays and signal coupling will be realizable in the 1970's. It is interesting to note that in the Western countries and Japan, work has been largely concentrated on gallium-arsenide-phosphide compound whereas in the USSR the work has been almost exclusively on silicon-carbide. Silicon-carbide, although having somewhat low carrier mobility has excellent high temperature and light emitting properties.

Microwave Technology

While up to present heavy emphasis has been placed on digital circuits, the next decade should witness the emerging of microwave technology. Two distinct aspects can be indicated.

First there is the problem of extending the power-frequency relationship (see Fig. B1). To date,the important microwave devices operating up to 4-5 GHz have consisted mainly of discrete silicon bipolar transistors. Their performance is reaching theoretical limits.

Also 4-5 GHz devices are primarily of the two terminal variety, which is the second aspect and as such have limited applications. Considerable effort is being expended to find three terminal devices configurations, that is,means of incorporating a control, or third, electrode.

Also,at present microwave devices tend to be noisier than vacuum tube counterparts. Improvements on noise performance is being actively researched and solutions can be expected by the end of the 70's.

High frequency generation will be pursued throughout the 1970's with maturity of this technology probably occurring in the mid 1980's. Some workers are predicting 250 kw pulses at 1,000 GHz.

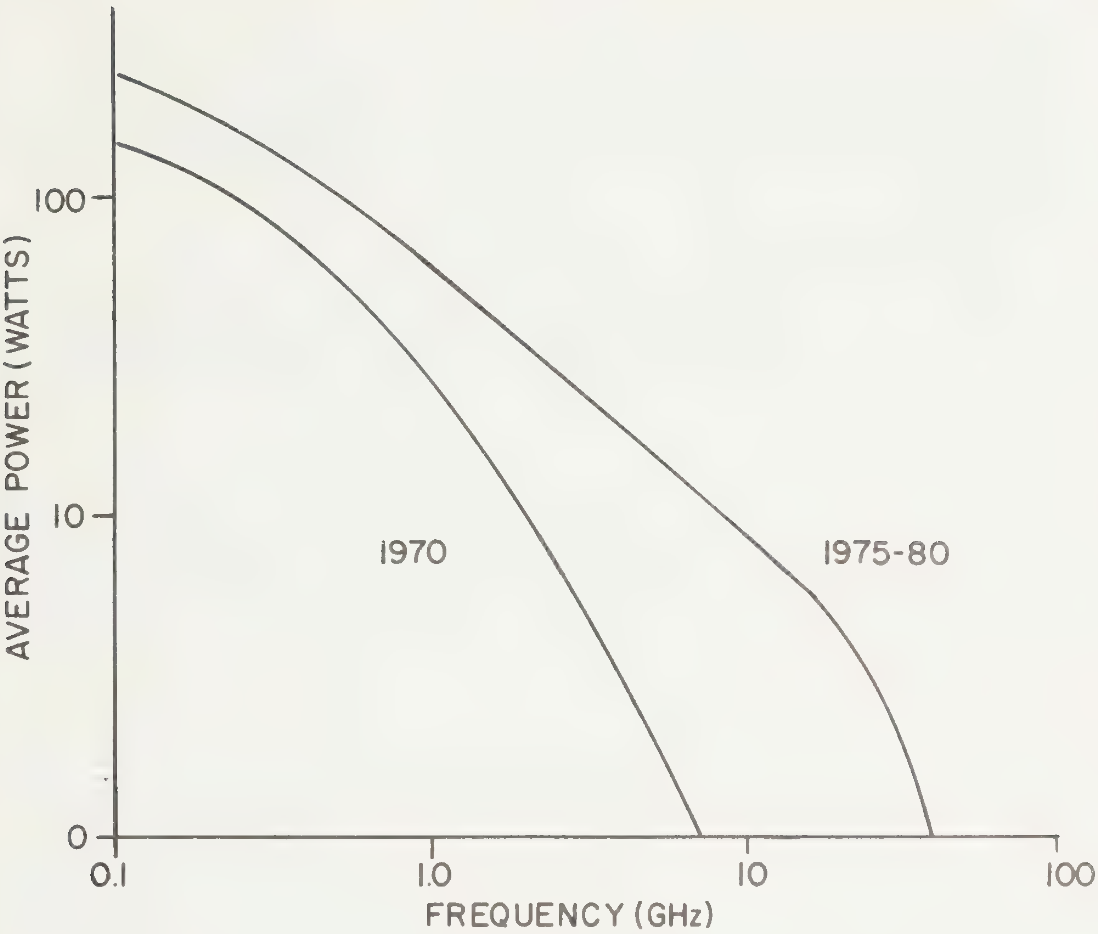

Fig. B1. Predicted power output/frequency trends for microwave solid state devices.

Emergence of New Technologies

Several interesting areas of research are at present being investigated which will give rise to new devices in the next two decades.

Amorphous Semiconductors:

Probably the best known form of this material is the "glass film" switch. Picosecond speeds are being claimed by some workers. Inexpensive organic semiconductor materials are also being investigated.

Electron Beam Junction Devices:

In this device a semiconductor space charge region is bombarded by an electron beam to produce electron-hole pairs. Current gains of 2,200 at 10 kev and rise times of 200-300 picoseconds have been observed. This is a three terminal device with potential microwave applications.

Surface Wave Devices:

This device makes use of the interaction between sound waves and electronics in a crystal. This phenomenon has also been called microwave acoustics.

Optical Interconnects:

Because signal propagation along an interconnect path of an integrated circuit can be as low as 1/50 of the speed of light, optical interconnects are being investigated for use where "inches" of distance are involved.

Epitaxial Films:

Growth of high quality epitaxial films on insulating substrates to give the required isolation and high propagation speeds is being pursued by many workers in the microwave field. Silicon on sapphire is one example of such techniques.

Magnetic Domains:

The "bubble memory", as is perhaps better known, is based on the properties of films of magnetic materials on certain crystal surfaces. Extension of technology, developed for the semiconductor industry, to these magnetic films, has enabled the production, retention, and manipulation of magnetic domains. Simple and densely packed logic functions and memories are possible.

Non-Volatile Semiconductor Memories:

The development of MOS memories led to structures incorporating insulators other than silicon dioxide. Layers of differing insulator materials on top of crystalline semiconductor (at present silicon) have been shown to retain charge for extensive periods. This charge can be introduced into the insulator structure in various ways (e.g., tunnelling, irradiation by energetic particles of electromagnetic waves, etc.). Once introduced, charge is retained without recourse to application of external power.

Conclusions

Three highlights of this brief survey stand out:

1. Silicon is the dominant material used today and will continue its dominance for the next 20 years.

2. New materials, particularly compound semiconductors, will become increasingly important in the microwave field and in special applications such as in the optical areas. Silicon carbide conceivably may become the dominant material for high temperature applications.

3. Integrated circuits of both the bipolar and metal-insulator-semiconductor types will dominate the market during the period. Considerably greater complexity and higher reliability, than that presently available, can be expected.

The semiconductor component market is large, at present in the vicinity of 1.5 billion dollars per annum. Of this market the USA holds the major share and probably will continue its dominance. Canadian companies have a place in which specialties or strengths, as in parts of the communications field, can be exploited. To be successful however, will require a highly concentrated effort together with innovations of advanced and automated techniques.

The large market is forcing exploration of every facet of the semiconductor band gap and its structure. It is thus natural that there will continue to appear a large variety of new device and circuit configurations each with differing electrical performance. As these enable us to perform progressively more complex functions in single miniature packages, so we can expect our systems designs to reach for theoretical limits.

3. COMPUTER TECHNOLOGY

Hardware and System Architecture

A continued expansion in size and numbers of, but no revolutionary changes in, large computer installations is predicted for the next five years. A prominent feature of the present scene is the accelerating utilization of small computers, which has been made possible by falling costs of logic circuits and memory. Simple graphical input-output devices are now fairly common, and more sophisticated units will be widely used in the next few years. These rapid changes, especially those at the low-cost end of the computer market,which will allow computers to penetrate many diverse areas of activity,will cause a qualitative change in our socio-economic environment.

In the 20-year period ahead the size of large computer installations measured by the effective number of instructions per second, will increase by one or two orders of magnitude per decade. Barring revolutionary developments, the raw circuit speed increase will be a good deal less than this, but increased effective speeds will be achieved by greater system complexity, i.e., by overlapping and parallelling of operations. Considerable gains can be foreseen in:

(a) fabrication of very complex integrated circuit arrays with propagation delays of 1 nanosecond or below and low power consumption.

(b) batch-fabricated fast memory of both semiconductor and magnetic types with cycle times as low as 10 nsec.

(c) microprogramming technology and techniques which will greatly change system concepts, increasing speed and flexibility

(d) bulk random-access memory. The exploitation of technologies such as coherent optics and/or electron-beam may provide capacities of 10^{12} bits with a few seconds access time.

Extremely low cost small computers will be mass produced. This will encourage decentralization of many functions but in spite of this the need for communication with larger computing installations will increase.

Graphic devices will become major, rather than minor, input-output devices. The interactive use of remote terminals will tend to replace the present batch modes of computer usage for many applications. Optical character readers will be common and voice communication with computers will continue to develop with increasing sophistication.

Software

Software is currently primitive and expensive to produce. The problem of writing programs for very large systems has not been satisfactorily solved. We envisage a much greater application of machines to the writing of their own programs with reduction in cost and spectacular improvement in effectiveness. Problems in the future will more and more be specified in a language which is natural and convenient to the user and then will be translated into the appropriate machine instructions by language processors which are produced with much less labour than today's compilers. The art of producing system software will develop so that large assemblages of diverse computing resources (hardware and software) can be deployed on a dynamic basis to meet the needs of users.

Reliability

Reliability will cease being a limitation on system size and complexity. More reliable hardware, error correcting codes, redundant hardware with self-checking will be used in the most economical combination to produce reliability compatible with user requirements.

Cost Projection

The cost of large installations now increases approximately by 10% per doubling of capacity. This trend should continue. The cost of small computers should decrease in the absolute sense (greater capacity at lower cost).

Effects

Implicit in all these projections is the notion that there will be large data banks in many locations throughout the country and that they will be accessed by a large number of people either through a simple terminal or through a computer installation.

Utilization of computer technology will force the use of digital transmission and electronic switching in standardized communication systems. We are not prepared to make a quantitative prediction of rate but we think it would be realistic to assume conversion of all major systems within a decade. A limiting factor will be the enormous capital investment involved.

The present estimated rate of growth of communication channel capacity of one to two orders of magnitude per decade will have to continue for at least another decade to serve the projected increase in computer installations. Continued automation of communications systems will also be essential.

Besides creating problems for communications systems operators and designers, computer technology will help to solve these problems. The capacity of managers and designers will be enhanced by problem solving aids provided by sophisticated computer systems. Computer technology will contribute directly to communications system development by making possible:

(a) automated switching centres.

(b) computer controlled allocation of communications system resources.

(c) dispersed switching centres for local traffic in places where present techniques are uneconomic or unworkable.

(d) queued storage in memory units at strategic points in communications systems.

4. OPTICAL TECHNIQUES FOR INFORMATION STORAGE

Introduction

Advances in optical and electro-optical recording techniques in the past few years have resulted in much improved, or new forms of compact data storage. These advances result in improvements in traditional optical stores, such as photographs or microfilms, and challenge the virtual monopoly of magnetic tape and discs in the field of peripheral computer stores.

Compact Data Storage

(a) Microfilm

(i) Computer Print-Out Systems

Microfilm systems today are finding new roles as useful forms of fast, silent computer print-out systems. Systems can provide print-out speeds which are ten times faster than mechanical line

printers. They can be used to print 132 character lines at 10,000 lines per minute. These systems are commercially available today, and will take over part of the computer print-out field from line printers.

(ii) Ultra High Resolution Microfilm

Advances in preparation of very fine grain film materials have made microfilming of microfilm possible. This has resulted in a product which could be described as, "ultra-microfiche". The state-of-the-art today allows 3,200, 8½ × 11" pages of information to be stored on a 4" × 6" plasticized film. The importance of this advance is in the enormous volume of data which can be mailed (for six cents in this country). Two companies have installed Systems to use "ultra-microfiche", the US Ford Motor Company and the Sears Roebuck Co. Further widespread use of ultra-microfiche depends on decreasing the cost of the read-out optics.

(b) Holography

Holography is a form of photography which does not use lenses. Therefore the density of data stored is set by the resolution of very fine-grain emulsions, and not by the quality of lenses, as is the case with direct imaging systems as are used with microfilm systems. Holographic stores can also trade resolution for grey scale and these can allow high quality grey scale information to be stored. (Microfilm is usually of binary, black and white, information). Furthermore, indexing of information in readout from holographic stores is not as critical as with microfilm stores. Holographic stores have been proposed for credit verification systems. The successful field implementation of such an application awaits the production of a cheap laser system (less than $100), on which much effort is presently being expended. This could be in the mid-1970's.

Holographic stores have also been proposed for read-only storage of computer data; and have achieved data densities of about 1.6 million bits/sq. in., corresponding approximately to 1,000 8½ × 11" pages of alphanumeric text. The memory need not be in the form of a thin emulsion but can be in a volume, and up to 1,000 holograms could be stored in a one cubic cm crystal. Development models have been produced in the US and are available today.

(c) Electron Beam Recording System

Electron beam recording systems, using scanning electron microscope techniques, can be used to store data on photo sensitive materials, and have achieved densities of about three million bits per sq. in. Optical readout systems can be used to transfer data from such stores to computers. These stores can provide about ten times the density achievable in magnetic tape or disc systems.

In other applications, for archival-type storage (with a required life-time of 100 or more years), photo-sensitive materials may not be desirable because of data deterioration. In these cases, data stored by drilling small holes in metal tapes using electron or laser beams can provide essentially permanent data stores.

Electron beam technology is capable of achieving the above results today. Limited use can be expected in the 1970's.

Impact of Compact Storage Technology on Communications

Many applications require that information from data stores be widely communicated with time delays measured in days. Compact data stores, mailed or shipped at appropriate intervals may well be the most economical method to achieve the maximum data transfer. Catalogue and credit verification material fall into this category of data. With the former there is no change in traditional postal methods of communicating information. With the latter it is not yet resolved whether or not the economics and speed required for credit verification can be met by direct two-way transmission from system customers to central data stores, or by provision of local store systems mailed at regular intervals; probably a mix will result. What is quite clear however is that credit verification will be one of the most important new forms of data transmission for the future.

What has been said above for credit verification is true also for transmission of computer print-out data, archival data, etc.

5. LASER TECHNOLOGY

Preamble

The laser must still be classified as a recent development on the time scale relevant to the implementation of large-scale changes in civil communications systems, even though it will soon be a decade since the first operating laser was constructed by Maiman in 1960. Although a good foundation of research has been laid in this decade much of the necessary development of practical and economical devices remains to be done. The optical communications engineer does not have the broad background of development to rely on that supports new developments in microwave technology, so it must be expected that progress will be relatively slower and more expensive. It is quite possible, however, that as the amount of data to be transmitted increases, optical communications systems will eventually become more economical for high data rate transmission than any of the other systems presently envisaged. It appears likely that other systems will be capable of satisfying trunk communication needs during the 20-year period in question and probably do so more economically than optical systems. The real question is whether or not requirements for communications capacity will be rising so rapidly at the end of this period that other high data rate systems will be supplemented by optical systems.

In fact, it is impossible to predict these demands in any detail. A much better and more positive approach is to ask to what uses a system of extremely large bandwidth would be put and then to look for economical ways of satisfying these potential requirements. From this point of view optical communications techniques could be envisaged as having a meaningful impact in the next 20 years and as becoming very important in the succeeding 20 year period.

Present and Projected Systems Capabilities

(a) Transmitter:

There are a number of types of lasers which are potential candidates for transmitters. Two of the more promising are GaAs semiconductor lasers and Nd YAG lasers. At present the GaAs laser requires a great deal of development in order to achieve the necessary bandwidth under convenient operating conditions. Nd:YAG lasers have been pulse code modulated at rates up to 2.25×10^8 bit per second per channel. This rate can be safely projected to increase by an order of magnitude over the next few years.

(b) Transmission:

Since the atmosphere occasionally becomes effectively opaque to optical frequencies (during fogs, snowstorms and heavy rainstorms), high reliability operation requires the use of enclosed transmission lines. There are two promising optical transmission lines. One is an open pipe with recollimating lenses placed at intervals along the pipes. This is a very low loss system and one kilometre test links have been demonstrated. In addition, several hundred channels can be resolved at the end of a six inch diameter, 50 mile long transmission pipe. Thus it is not unreasonable to project a capability of 10^{12} bits/sec for such a transmission line in five to ten years. The chief problem is that pipes have to be accurately laid and arrangements must be made to correct for the effects of soil movement. The second type of optical transmission line is an optical fibre. Each fibre can carry at least 10^9 bits/sec and since these fibres are very small and flexible large numbers can easily be bundled together. This is a relatively lossy type of transmission line, however, it appears likely that a loss of less than 20 dB/km will be achieved.

(c) Receivers:

The basically limiting component here is the optical detector. At present the capability is about 5×10^9 bits/sec in the visible part of the spectrum and this seems likely to be increased to 10^{10} bits/sec in the next few years. The receivers, then, should not be a limiting factor for most envisaged systems. Also the possibility of using superheterodyne systems has been given some promise by recent developments in parametric optical devices which could be used as local oscillators.

Summary

Optical systems look very promising for the transmission of very high data rates (10^{12} bits/sec). Requirements for the next 20 years projected on the basis of current modes of usage of communications could probably be more economically satisfied by other systems. However, social planners are pointing out with increasing frequency the desirability of implementing services such as central library and data banks readily available to the general public through home consoles, education in the home, transaction of much business from the home, etc. Optical communications systems hold promise of economically providing sufficient bandwidth capability to make these schemes possible.

In addition, the narrow beamwidths and relatively interference-free transmission make optical systems attractive for some space and satellite applications such as satellite-to-satellite communication.

6. TRANSMISSION TECHNOLOGY

Guided Wave Transmission

There are four major mediums for guided wave transmission — twisted pairs, coaxial cable, millimeter waveguide and the "light pipe". They are not much affected by external fields, and do not radiate significantly. Losses increase linearly with transmission path length; the loss in the wire systems is due to skin effect and increases with root frequency, while the waveguide and "light pipe" mediums do not have appreciable frequency variation in the usable frequency band. There are two light pipes of significance for transmission, the one a fiber (two micron diameter) coated with another dielectric (50 micron) forming an optical waveguide, the other a pipe to allow unimpeded straight line transmission to a light beam. Installation on or in the ground is necessary; costs vary greatly depending on terrain. The cost per channel may be reduced by having many transmission paths in one physical structure; thus some sheaths contain 1,100 pairs or more, some coaxial cables 20 tubes.

Pairs are used for low capacity voice transmission (< 24 channels), for pictorial telephone, and specially constructed cables with low crosstalk are used for television transmission. Existing digital transmission systems in Canada use pairs at 1.5 Mbits/sec rates. New systems at 6 Mbits/sec on pairs and at 16 Mbits/sec using specially constructed cables are being introduced in other countries. There are cable constructions spanning the region between twisted pairs and coaxial cables.

Coaxial cables are used in Canada for television distribution, using 12 channel systems with 1/2 mile repeater spacings, and 20 channel systems with 1/3 mile repeater spacings. Wire line entrance links from radio sites to city centres, and medium capacity (240 channels) are common in Canada. High capacity long haul analogue transmission on coax is common in many countries; the largest systems have 3,600 channels,

	LOSS/MILE	BANDWIDTH
22 ga. paired cable	26 dB at 1 MHz	several MHz
0.375" coaxial cable	41 dB at 100 MHz	several hundred MHz
2" copper waveguide TE_{01} mode	3-4.5 dB at 60 GHz	about 65 GHz
light fiber	now about 160 dB expect 32 dB to be attained	about 1 GHz
light pipe	about 1 dB (due to lenses)	1,000 GHz

a repeater every two miles, and cost $2./channel mile. Analogue systems carrying 9,600 channels are planned. Digital systems are planned, at 100 Mbits/sec using 0.174" tubes, and 300 and 600 Mbits/sec using 0.375" tubes; costs are comparable to analogue systems. Very high capacity analogue systems require short repeater spacings and very linear amplifiers, while very high capacity digital systems require broadband amplifiers and cable-tracking equalizers. The choice between an analogue or digital system, while partially economic, is also based on the types of traffic — a digital system does not have to be engineered for many types of traffic.

Millimeter waveguide systems operating in the low loss TE_{01} mode are now technically feasible, and installations in the US and Japan appear certain in the second half of the seventies. A typical system uses digital phase modulation at a 300 Mbit/sec rate, a 1 GHz channel separation, and repeater spacings of 15-25 miles. The guide itself, a 2" round copper tube, has either a dielectric coating and/or a helical winding in it; improvements in knowledge of dielectric coatings may allow significant loss reduction. Capacities of 250,000 channels are planned and increases are possible with improved modulation techniques, closer channel spacings, and reduced losses. The guide itself must be manufactured and installed carefully to minimize reflections and mode conversion.

The fiber optic light guide requires development of a low loss guide and a room temperature semi-conductor source. The fiber's flexibility and small size makes short haul application attractive. Adequate detectors are available. There are many technical problems unsolved for this type of medium, and large scale application in the seventies is remote.

The light pipe allows communication engineers a great deal of flexibility — permits spatial, frequency and time multiplexing. This is

offered by laser sources of short (picosecond) pulses, with small beam-width allowing many beams (600) in one pipe with adequate resolution, and various color possibilities. Capacities of greater than 2,000,000 channels with 50 mile repeater spacings are contemplated. The pipe itself must not move to interrupt a beam; either it must be kept invariant under ground movements, or the beam bent. Despite a glowing promise, uncertainties about feasibility, reliability, cost and size make these systems not commercially implementable in the seventies. But inexpensive systems appear attractive in the eighties if a need for very high capacity is encountered.

Guided waves permit many options to communications engineers. It will be primarily improvements in semiconductor and electronic devices that will hasten their use. The optical waveguide needs development, and we expect improvements in other guides.

Radio/Satellite Transmission

Introduction

The basic technology of radio transmission does not appear likely to change dramatically in character in the foreseeable future, although advances in circuit technology will undoubtedly result in cheaper, smaller and more reliable terminal equipments. The need for radio transmission is continually increasing and advances in technology are continually adding to the Frequency Spectrum that may be used. However, ultimately there is a limit to the total usable frequency range. Also, there are other users of the available frequency space such as radar; remote control; radio astronomy and survey instruments, who compete for frequency allocations. Hence, techniques must be devised to minimize the mutual interference effects. Such techniques may include time interleaved transmissions, transmissions with maximized information content, and planned sharing of frequency space.

Transmission Techniques

The radio transmission techniques that can be foreseen for the future are mainly those that exist today.

(a) Microwave Relay

This technique provides the backbone of the present long haul heavy route communications systems in Canada, as well as many smaller capacity systems. Most of the equipment operates in the 4 to 6 GHz frequency bands. For example, a fully complemented route in the 4 GHz band could carry about 12,000 telephone circuits in a 500 MHz band. Many of the routes are presently operating below this capacity and in the next five to ten years will be gradually expanded up to capacity by the addition of radio transmitters and receivers. New routes will continue to be installed, especially in out-lying areas.

The use of microwave radio for this type of service beyond this period will depend upon the assignment of new frequency bands in the

10 to 30 GHz region where the use of wide bandwidths and digital coding techniques will provide a route capacity of 30,000 telephone circuits. The use of digital signalling techniques will also permit greater route densities and hence increased capacity. The feasibility of this type of service and its capability to overcome rain attenuation problems has been demonstrated and it will likely prove attractive economically in comparison with cable, waveguide and satellite systems between five and fifteen years into the future.

(b) Satellite Relay

Present communications satellites are located in geostationary orbits and have earth illuminating antennas. We may project a continuing advance in the capability to place and maintain powerful satellites with narrow beam, fixed or steerable antennas in accurately specified positions.

Communications satellites currently are used to carry telephone and television signals between continents and are planned to provide communications within Canada. Within the time period 1970-1989, satellite relays have the potential to provide unique services in addition to the trunk facilities and TV distribution facilities that can be foreseen in the immediate future. These are:

(i) Direct communication between points in a geographical area eliminating the need to detour communications through terrestrial nodal points.

(ii) Assignment of circuits between earth terminals on demand to provide for changes in channel requirements and traffic destination.

(iii) Relay of data from a wide variety of sensors located over a large area for geological, meteorological and other purposes.

There are ultimate limitations to the capacity that can be provided by satellite communications. This limitation is imposed by the total bandwidth available for the service and the limited number of orbital positions available for the location of satellites. For example, if an orbital arc of 10^{o} is mutually visible from terminals in a selected region, and antennas 40 feet in diameter operating at a frequency of 4,000 MHz are used, then six satellites may be spaced at 1.6^{o} intervals. A total capacity of 128,000 voice channels in a 500 MHz frequency allocation would then be possible using available modulation systems. Using advanced modulation techniques, capacity could be increased by a factor of four to five. However, a limited number of frequency allocations can be made for this service, and eventually, further increases in capacity will have to be provided by terrestrial means.

(c) Troposcatter

This technique is used mainly for low capacity communications (120 voice channels) to remote areas and is not capable of carrying TV signals. Its use may be continued in special areas, but because of the high cost of terminals and maintenance problems, most existing circuits will likely be replaced by other facilities, probably satellite relay.

(d) Mobile Radio

The need for mobile radio for internal city communications (for police, fire, taxi and commercial services) will continue to expand and will exert pressures for additional frequency assignments. Improved electronic circuitry, digital calling techniques and time sharing of the spectrum will provide better service and better utilization of the spectrum but demands are likely to exceed the technical capabilities to provide the required service.

(e) High Frequency Radio

This technique is used mainly for low capacity communications (one voice channel) in remote areas or between mobile terminals. It cannot provide very high data rates or very low error rates. However, it has the desirable characteristics of low terminal costs and portable terminals.

(f) Personal Radio

Personal radio includes both paging devices and two-way communication sets. The gradual increase in the use of both of these will probably change to a much more rapid growth-rate in the late 1970's. Beyond this, it may be possible to introduce personal telephone transceivers linked, to a limited extent, with the central switching system. Congestion problems in the radio frequency spectrum will probably restrict the use of these radio systems to local areas or to institutions where electromagnetic screening can reduce internal interference. Miniaturization techniques and selective calling and time sharing modulation techniques existing today indicate that such a service could be developed in a five to ten year period.

7. INPUT-OUTPUT TECHNOLOGY

Introduction

Input-Output devices are the part of a communications system with which users have direct contact. The successful introduction of terminal devices is therefore quite sensitive to user demands which depend on many sociological and economic factors. Because this forecast is based mainly on technological considerations, it can only catalogue the developments that might be available to meet these demands.

Aspects

Displays

At present, CRT's predominate for the presentation of visual images and multiple character alphanumeric displays. For data displays of only a few characters, ionized gas and luminescent electrode tubes such as

Nixie tubes are the most common although light emitting diodes and gas plasma panels are becoming competitive. Still in the laboratory stage are the liquid crystal, electro-luminescent panel, and magneto-optic displays.

In contrast to solid state displays, CRT's have inherent limitations on brightness, reliability, ruggedness, and their power and voltage requirements are incompatible with silicon devices. Present limitations of cost and size for solid state displays such as LED's are not inherent limitations and can be overcome by further development.

Although the use of tube displays will expand in the near future, they will be largely displaced by solid state devices for data display applications by the end of the decade. Solid state devices capable of presenting high resolution, large area, color, and half-tone images will not appear in the field for at least 10 to 15 years.

Hard Copy Devices

As the communication, storage and retrieval of data electrically becomes more widespread, the printed page will become less important as a means of transferring and storing information. Looking at the shorter term, however, the newest generation of alphanumeric printers is characterized by fewer mechanical parts, higher speeds, and less noise. Competing to replace impact printers are the deflected ink jet method and the electrostatic, migrated carbon method. Both of these have the inherent capability of producing graphics as well as alphanumerics.

Character Recognition

The comments made previously about the printed page also apply here; the implication being that automated page readers may not be necessary in the future.

Existing optical character recognition devices are capable of reading up to several thousand characters per second with error rates of 0.01%. They are designed either to recognize a small character set in a variety of fonts or all the characters in one font, usually the OCR-A font. Their high cost makes their use justifiable only where large volumes of data must be read.

Speech Recognition

Current research is largely directed towards identifying and extracting the fundamental features of speech that form recognizable patterns. There are several approaches which differ in the types of elements into which the speech is segmented and also in the features used to identify these elements. In general, recognition rates can be improved by applying linguistic constraints such as the probable combinations of phonemes to the initial segmentation. Any practical development will require the machine to repeat each word for verification. Development work is being expedited by the availability of cheaper computing power and integrated circuit active filters.

Image Sensors

Solid state, self-scanned image sensors are being developed which, when compared to present vacuum tube sensors, offer the advantage of size, reliability, low voltage operation, and the potential cost reduction of integrated circuit techniques. Experimental devices have been built using monolithic silicon technology and also thin film technology, but solid state sensors as replacements for TV camera tubes are probably five to ten years away.

Acoustic and Strain Sensitive Transducers

The carbon transmitter (microphone) unit of the telephone set will begin to be displaced by electret units with semiconductor amplifiers in the early 1970's. The electret is an insulating film structure which can be electrically polarized in a manner analogous to the magnetization of a permanent magnet. These units will offer much lower distortion of acoustic input signals and will operate on much lower loop currents than is now the case.

Semiconductor strain sensitive devices should replace mechanical contact structures associated with keyboard pushbuttons in some applications starting in the mid 1970's.

8. POWER SOURCES TECHNOLOGY

Introduction

Predicting the trends in electrical power sources over a 20 year period must take into consideration three basic categories (a) central power station, (b) transportable power and (c) non-air breathing systems. Normally the time required to discover, develop and manufacture a new source of power exceeds 20 years. The introduction of solid state devices which promised lower power needs per channel has merely slowed the continuing growth of power consumption for communications. The greatly increased volume of traffic to be handled has been mainly responsible.

Generally, the raw energy costs for a system served by an electric utility are a minor fraction of the overall costs of installing and operating the system. Often the exact opposite is true for remote ground stations and for mobile systems of many kinds, especially those in space or under sea where atmospheric oxygen is not free. To avoid costly mistakes it is strongly recommended that system planners take power supplies into consideration from the very beginning.

Central Station Power

Central generating stations are unlikely to change significantly during the next 20 years. These will continue to be based on falling water, fossil and nuclear fuels and will feed into distribution grid

systems from which large stationary communications installations will draw their power. It is anticipated, based on information from a typical regional system, that the demands for power from the central generating stations will be at least double present demands by 1990.

Transportable Power

Small transportable equipment has been traditionally powered by either batteries or small gasoline motor generators. The recent availability of inexpensive small motor generator units (up to 1 kW) has led one worker in the field to consider the possibility of the throw-away concept as it might prove less expensive to replace the entire unit than to stock replacement parts and conduct major overhaul.

The emphasis on and the possibility of enactment of antipollution laws has accelerated investigations of the gas turbine, the Rankine, Stirling and rotary engines as well as methods of reducing the amount of noxious substances in the exhausts of conventional prime movers (internal combustion, diesels etc.). One of the advantages of the Rankine, Stirling, turbine and rotary engines is the greater horsepower/pound ratio over that of current IC and CI types. The cost of small turbine engines is expected to fall sharply during the 70's as manufacturing methods are improved. Canadian industry has a well-known competence in the small turbine field. The other multi-fuel engines may achieve a significant market penetration into Canadian equipment by 1990. Development of a Canadian capability in this field should be encouraged strongly.

A presently-available silent source of continuous power is the thermo-electric generator. These are long lived relatively low wattage devices capable of operation from a multitude of low grade fuels. Overall efficiency is low but reliability is high. They will continue to serve a well defined need until a better solution is found.

Non Air-Breathing Systems

While development of fuel cells was proceeding as part of the Gemini and Apollo space missions in the 60's the costs per module gradually came into sight and the operating time between major overhauls was increased. The fuel cell is most attractive as it is classed as a silent power source. When coupled with a secondary battery system it should be even more attractive because of its increased flexibility in meeting changing power levels such as encountered in transmit/receive application particularly for the larger units.

No dramatic developments are anticipated to parallel the spectacular technical successes of the 60's, however steady progress can be expected. The hydrocarbon/air system may become one of the systems chosen for one new transportable communications system scheduled for the late 70's and others may follow before 1990. There is some Canadian work in progress which could accelerate possibly the introduction of liquid fuel batteries into Canadian communication equipment, but it would have to be expanded and reoriented. An off shoot of the fuel cell development has been the high rate metal air cell. The metal air

cell with capability of mechanical recharge should be very attractive for use with small portable units. A Canadian company is presently conducting R&D on the zinc/air system.

Recent information indicates that power requirements for satellites will increase 20 fold over ISIS B by 1980 and the following decade could follow this trend. The primary source of power will likely remain the sun, with conversion by solar cell array. The rate at which energy can be collected is determined by the size of the array and the efficiency of the converters. To meet the power demands on future satellites during eclipse periods it is essential that more efficient use be made of the energy storage devices on board the spacecraft. The introduction of proper charge control would permit more efficient use of the Ni-Cd system. The H_2O_2 fuel cell as a rechargeable battery, expected by the mid 70's, offers the possibility of greater energy and power densities. The cost and dangers of radio-active pollution still remain as problems with the radio-active isotope fuelled thermo-electric generator for space use. At least for the next generation of satellites the nickel cadmium solar cell combination will be used with a charge control system to maximize utilization of the capacity of the battery.

For terrestrial applications it is anticipated that the majority of requirements will continue to be met by the traditional work horses of the secondary and primary systems, lead acid, Leclanche and zinc mercury systems. The greater capacity of the manganese alkaline and reported long shelf life of the magnesium primary cells will undoubtedly make inroads where the advantages justify the increased cost. The development of the reserve primary configuration of all the systems promises a reduction in total inventory to be carried and new battery performance when activated. This is a particular advantage in remote areas where transportation is costly and unpredictable.

The use of active chemicals in non-aqueous electrolytes, which deliver higher voltage and energy per cell, promises an increase of five to ten fold in the energy density. It is anticipated that prototypes will be available before 1980.

The possibility of self-energized integrated circuit modules stems from the discovery of a new salt of rubidium, silver and iodine which has an expanded lattice structure with very good ionic conduction. Solid state batteries based on this electrolyte were invented and are being developed. The potential now exists of depositing the battery as a unit of the integrated circuit. It is expected that a Canadian industry will be undertaking in the near future an investigation of the problems involved with mass production of this type of battery.

Figure B2 shows the predicted power sources for various power levels and mission duration. The small arrows indicate the direction of developments.

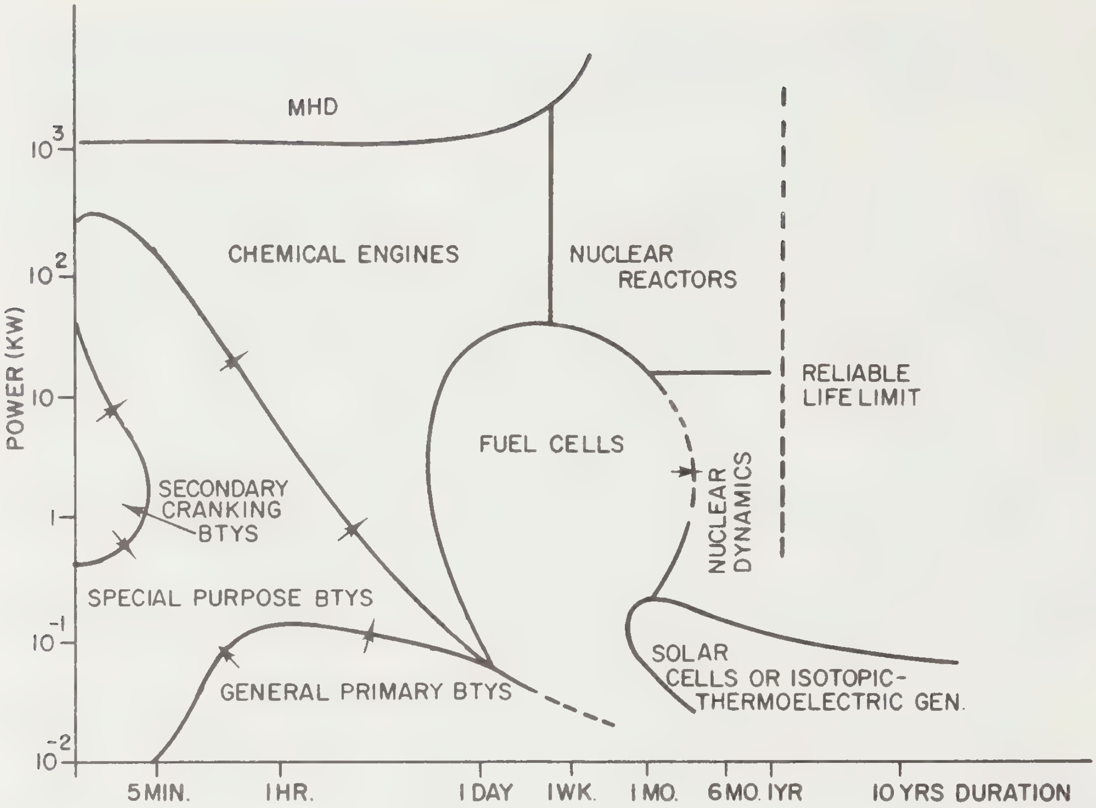

Fig. B2. Uses of electrical power sources.

9. ANALOGUE AND DIGITAL FILTERING

Introductory Discussion

Most filtering and frequency shaping functions today are performed by passive RLC networks. The mathematical foundations for LC network synthesis were firmly established and almost completely automated by the early 1960's. The synthesis techniques provide optimum solutions for LC type networks. No general solution exists for lossy RLC networks, but computerized optimization techniques are widely used.

The passive network design techniques serve as a standard of comparison for new techniques as they emerge. However, no general replacement has been found for RLC networks. In special applications, new techniques are proving superior. For example, active filters have very definite performance advantages at low frequencies.

The trend to medium and large scale integration of digital circuits will favour development of digital filters.

Transmission of information by pulse code modulation systems will demand time domain filtering.

Techniques of Filtering

(a) Passive RLC Networks

Design methods for LC lossless networks are based on precise analytic solutions developed over the last 20 years. The number of components is minimized by these techniques.

Approximation of the desired amplitude frequency characteristic is the usual design objective. Delay equalization is routine using numerical approximation algorithms.

Therefore, design methods for RLC networks cover virtually all required practical problems and these networks can be manufactured with available inductors, capacitors and resistors.

Discrete components are generally used to fabricate RLC networks. This will continue for many years since the inductor must be individually wound. This fact will encourage replacement of RLC networks by active or digital filters where economically feasible.

Below about 20 MHz, the inductor is fabricated using a wire coil inside a ferrite pot core of high permeability. A typical production cost range is two to three dollars. The element is stabilized for temperature by gapping the ferrite material. In the VHF range, inductors are wound on a former using a ferrite tuning slug for inductance variation.

Ferrites will be improved gradually over the next 20 years but no dramatic developments are foreseen.

Polystyrene and mica capacitors are very widely used for critical filter applications. Only modest improvements may be expected in size and performance for these components. Currently these capacitors cost about forty cents for a one percent tolerance unit.

In recent years, stable ceramic capacitors have appeared on the market with a fraction of the size of mica or polystyrene and comparable performance. These ceramics are expected to be cost competitive within five years.

In summary, the RLC passive networks will continue to be important for the next 20 years. Their share of the overall network production will drop considerably over this period. More significantly, their limitations will probably not determine system design to the same degree as in the past.

(b) Active and Distributed Networks

The development of inexpensive (less than one dollar) operational amplifiers used with thin or thick films resistors and capacitors have made the active filter competitive in the low frequency range. Currently, economics dictates that this region is approximately below 20 kHz.

The design techniques are well established for active filters. Considerable emphasis has been placed on methods which reduce sensitivity to component variation to tolerable levels. Most active filter realizations require resistor capacitor tolerances of one percent or better. In extreme cases, .05 percent tolerance may be required. This rules out fully integrated silicon active filters. Hybrid thin or thick film technology readily achieves the required tolerances. Design techniques can be chosen to suit the process available.

Distributed resistor capacitor networks can be realized using thin film technology. There has been limited application of this technique.

Future Trends

Active filter applications will broaden as new low cost operational amplifiers with better gain-bandwidth product are developed. Within several years, active filters will be competitive to 100 kHz and usable to a few MHz. Filter assembly will become more automated with extensive use of thick and thin film networks. Filter tuning will be by automatic machine resistive trimming.

The inherent limitations of active filters such as power drain, power linearity, limited dynamic range will prevent a complete switch from passive to active.

The use of standard hybrid building blocks with operational amplifiers will become common and minimize development problems.

Special applications such as space communications, power filtering and signal processing will favour active filters.

The active filter power requirements will also be reduced by better system design and improved operational amplifiers.

Distributed networks will be more widely used in future with the wide bandwidth operational amplifiers.

(c) Crystal Filters

Most present narrow band designs are realized using an economy bridge with transformers and discrete crystal units. Crystal resonators are also used to achieve sharp cut off ladder filters. The monolithic filter is becoming common for narrow bandpass filters in the range 3-30 MHz. Current price of a two pole filter is about 25 dollars.

Future Trends

Monolithic technology will fill the requirement for virtually all narrow passband filters over an extended range of 2-60 MHz. Improvements in processing will make possible stable, low cost single sideband filters for frequency division multiplex channel banks within five years.

Crystal technology generally will improve mainly from better processing methods and controls.

The requirement for crystal bandstop and ladder bandpass filters will continue for many years. However, the trend to digital transmission systems will reduce the need for crystal tone selection and blocking filters.

(d) Digital Filters

Currently, very few digital filters are used in communication systems. Some applications are data and signal processing.

Future Trends

Large scale integration of digital processors such as memories, shift registers, adders and multipliers will make economical the application of digital filters to communication systems. Already, MOS read-only memories are available as LSI with 4,096 bits per chip with cost approaching two cents per bit. MOS shift registers are currently about five cents/bit.

Arithmetic units with integrated 12 bit adders and seven bit multipliers will be typical building blocks for digital filters. Integrated or compact hybrid analogue to digital and digital to analogue converters must also be developed. Delta modulation can achieve the necessary A-D and D-A conversion with a minimum of analogue components.

Within five years all the required devices should be available for economical communication systems using digital filters. The low frequency range (less than 100 kHz) is most suitable for digital filtering because of limited speed of low cost MOS devices. Therefore some systems will require both digital and LC filtering for best economy.

(e) Special Filters

(i) Mechanical and Ceramic

These filter types are used for narrow passband applications from 40-600 kHz. A stable mechanical resonance is used to achieve filtering action.

Future Trends

Further application is limited because the equivalent inductance capacitance parameters cannot be controlled as well as the frequency of resonance. These filters will likely continue for special applications. For example, low cost ceramic filters will continue to be used for IF filters in some domestic radios.

(ii) Microwave Filters

Present filters in this region are limited in performance by available components. A combination of quarter and half wavelength resonators and resonant cavities are used. Waveguides, microstrip and striplines are used in practice. For low loss, the expensive machined waveguides must be used.

Future Trends

The availability of good microwave transistors will permit extensive use of active microstrip filters with gain. Filters will become very compact with simple manufacturing methods. Wider bandwidths will be possible with these new components.

(iii) Transversal or Tapped Delay Line Filters

Digital pulse transmission systems can be well equalized by the transversal equalizer. These can be made adaptive to handle time varying channels.

One current commercial application is the adaptive equalization of telephone channels to transmit 9,600 bits/sec.

Future Trends

The acoustic surface wave filter will permit economical transversal equalizers to approximately 100 MHz. New low cost wideband operational amplifiers will also assist this trend since the tap points require buffering and summation.

Influence on Systems Design

The availability of low cost digital filters will change system design to exploit this fact. Past communication systems, particularly frequency division Multiplex (FDM) equipment was designed on the known performance of LC filters. Similarly, future systems can be expected to depend on digital filters.

FDM channel banks may also be designed using crystal monolithic filters. Again, the system design will be altered to exploit the monolithic filtering properties.

The properties of active filters will also have some influence on system design.

Filter performance at low frequency is superior with active networks in contrast to poor performance of passive filters. The limited dynamic range of active devices will also be considered in system design. Amplifiers and filters will tend to lose their distinct identity in an active filtered system.

Future optimum systems will exploit the best features of all filter types. Various combinations of filters can be expected to emerge even in the same class of systems.

10. OTHER DEVELOPMENTS ARISING FROM THE PHYSICAL SCIENCES

Introduction

As our field of discussion we took all subjects which would not normally be considered as falling under the previous sections 1 to 9. Some subjects we eventually discarded because we felt that they would not contribute to communications within the foreseeable future. As a matter of interest we list these subjects: high strength materials, fluidic technology, biochemical memories and extra-sensory perception. Three subjects were dealt with in more detail; our conclusions are summarized below.

Microwave Acoustics

This phase refers to the propagation of acoustic waves with frequencies in the 10^8 Hz range along the surfaces of solids. Piezoelectric materials are predominantly used, because of the great convenience of being able to use electrodes, evaporated on the surface of the material, as generators and receivers of the surface waves. These surface waves (Rayleigh waves) are non-dispersive, and have typical wavelengths of about three microns (3×10^{-4} cm) at a frequency of 1 GHz. Propagation losses are of the order of 0.5 to 1.0 dB per microsecond at 1 GHz, and increase as the square of the frequency.

Because of the small wavelength, a similar technology to that used in integrated circuits and microwave stripline is applicable to microwave acoustics. The receiving and transmitting transducers are usually inter-digitated electrodes evaporated on the surface of the solid at separations of one-half wavelengths. Mass loading of the surface can be used to channel the surface waves. By using semiconductor materials, either in bulk or in contact with a piezoelectric material, amplification can be achieved through the interaction of surface waves and current carriers.

The possibilities of such acoustic devices include delay lines, couplers and bandpass filters, and focussing devices similar to optical lenses. The field should develop rapidly in the next five years, dependent on the development of photolithographic and evaporation techniques to achieve the edge definition and precision in the surface configuration of metal layers for control of the waves.

Amorphous Material

Amorphous materials have several advantages over the crystalline materials at present used in solid state devices. These materials are cheap to manufacture, are mechanically rugged, and have the possibility

of being cast, extruded, evaporated, painted, etc., into a great variety of physical forms. Devices made from such materials are also likely to be radiation resistant.

An important class of device which could be made from amorphous materials is as a protection of solid state components in telephone systems from overvoltage spikes such as those resulting from lightning strokes. Solid state components which are now replacing relays, etc., in telephone systems require better protection from such spikes, and it is likely that amorphous material devices, which may be electrically symmetrical and of low capacitance, will become important for this application.

Amorphous materials also show promise as memory devices which will not lose information in the event of a power loss. The limiting size of such memories would probably be due to spatial limitations caused by the necessity of access wiring rather than the limitations of the material itself.

At the moment the electronic energy spectra and transport mechanisms in these disordered solids is only partly understood. Because of this,and because of the vast number of new compounds which could be manufactured, it would be reasonable to expect that new effects, higher speed devices and higher mobility materials will be discovered in the next few years. It should be remembered, however, that the production costs of the materials will have to be very low, in order to compete with the present very efficient silicon device technology.

New Superconductors

A superconducting material, when cooled below its transition temperature, has zero electrical resistance. At present, all superconducting materials have transition temperatures which are below the boiling point of liquid nitrogen (-196^{o}C or 77^{o}K). If a new superconducting material is discovered which has a transition temperature above 77^{o}K, then the cost of cooling the material will be vastly reduced, and large scale engineering applications of superconductors will become feasible. Such a superconductor would be very useful for reducing losses in electrical applications where adequate cooling can be economically provided. Since present superconductor theories do not allow the transition temperatures of known superconductors to be predicted, it is a matter of chance whether new superconductors with significantly higher critical temperatures will be found. There is a theoretical possibility that new superconducting materials will be found among the transition metal oxides, in contrast to the metal alloys which form the basis of present day superconductor technology. If such a possibility exists, it should be realized in the next five years. The eventual application to communications transmission would appear to need a breakthrough of considerable magnitude and the balancing of the costs and feasibility of the needed refrigeration procedures against the benefits produced by elimination of amplifiers.

APPENDIX C

THE DOMESTIC USER*

Broadcasting — Program Origination, Distribution and Diffusion of Educational or Entertainment Programs

CONTENTS

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* Contributed by: J. Miedzinski, CRTC
and S.F. Quinn, CBC

1. INTRODUCTION

1.1 DEFINITIONS

Broadcasting is a method of radio communication using the medium of Hertzian waves in free (i.e., unguided) propagation[1]. In common usage the word broadcasting is employed in the restricted sense of mass communications only. This excludes telecommunications systems with limited numbers of users and/or two-way systems (paging, taxi, air and sea communications networks) even though the physical principles employed in the latter cases are the same as in conventional broadcasting.

Diffusion is the process of delivering signals directly to individual recipients. Diffusion may mean, simply, the transmitter-home-receiver broadcasting link. It may also be used to include the community antenna cable system, or cable system for short, between the transmitter and the home receiver.

Distribution is the process of delivering information to the diffusion centres.

1.2 THE GROWTH OF THE CABLE SYSTEMS

Cable systems for television signals have grown rapidly in urban areas, in recent years, to fill a demand for better quality reception and for more TV channels (from out-of-town stations). Approximately 23% of urban households in Canada are subscribers to some 317 cable systems[2]. The systems are physically independent and the longest path length extends no more than 35 miles from source to receivers. It is anticipated that there will be a continuing growth in cable systems, encouraged in part by new developments in technology.

An attraction of a cable system is that it has the potential to supply the subscriber with many more services[3] than are now available 'off air'. It is interesting to note that 35 systems in Canada are offering programs by cable that have not been received 'off air', some of these programs are films, some educational television provided by local authorities, some council meetings and talks by the mayor or parish priest[2].

1.3 THE 'HOME ELECTRONICS CENTRE'

The central element of new developments in communications technology, for the domestic user, is that they allow greater variety and multiplicity of program choice[4]. The term 'home electronics centre' has

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[1] Radio Act, Page 3.
[2] Broadcaster, December 1969.
[3] See section 3.4 below for description of potential services.
[4] This theme is explored in the Final Report 'President's Task Force on Communications Policy, Chapter seven.

been coined to describe the total facility that technology can provide in future urban homes. For example, new technological developments will allow, sometime in the near future, use of an attachment to the home receiver to playback audio-visual programs from cassettes that can be purchased or rented like books or phonograph records. But capital cost militates against the swift implementation of new technologies. Looking backwards in history, an example that comes to mind is color television, which was introduced commercially in the USA in 1954, and in Canada in 1966. About 10% of Canadian TV households now have color sets, and about 65% of CBC programming is in color.

A brief review of the basic features of broadcasting and cable systems is presented below and a forecast of the implementations of technological developments is made. It is likely that broadcasting as we know it today, will evolve to take a new position in the gamut of communications technologies side by side with the newcomers.

2. BROADCASTING

2.1 BASIC VALUES

Among the many advantages of broadcasting, one should make a clear distinction between the fundamental and the incidental advantages. There are only three fundamental advantages:

1. Virtually instantaneous communication.
2. Freedom from a solid connection between the transmitter and the receiver.
3. Capability for omnidirectional transmission.

The last two advantages result in the following main features:

(i) Communications to receivers in the air or on or across the sea or across impassable terrain. Portable radio and television receivers are an important example of this feature. The short wave program of the International Service is another example.

(ii) Communications to non-responding receivers at unknown locations.

(iii) Simultaneous communications to a virtually unlimited number of receivers without any modification of or cost addition to the transmitting system.

The first of the above features is common with certain telecommunications systems. The second and the third are unique to broadcasting. This is, of course, a matter of common knowledge, yet it is worth restating because the current technological revolution often gives the impression that nothing is constant any more. It is true that new technologies may replace broadcasting in many applications, particularly

where the use of broadcasting is based on an economic advantage. However, when any one of the three features is required, broadcasting will not be replaced in the foreseeable future.

2.2 BASIC LIMITATIONS

The fundamental limitations of broadcasting are just as few as the fundamental advantages. We may list:

1. Dispersion of transmitted energy with square of distance from the source.

2. Significant absorption and dispersion in the atmosphere at higher frequencies.

3. Interference between signals from different sources co-existing in space, time and frequency (or even at different frequencies, if some are sufficiently stronger than others).

These disadvantages represent the inherent result of omnidirectional transmission through the natural medium. The last one is the most significant and is the prime reason for the regulation of broadcasting by national and international bodies.

2.3 SPECTRUM USAGE

Already, more than one-half of the usable spectrum below 1 GHz is assigned to broadcasting. There is considerable congestion in parts of the spectrum assigned to broadcasters, for example VHF/TV. However, the UHF band, TV channels 14-83, is largely untapped. At the present time there is no usage of UHF in Canada except for a few five watt transmitters in small communities. The first high powered UHF transmitter is likely to be working in Toronto, Channel 19, in 1970. The present Canadian UHF television allocation plan provides for a maximum of seven separate additional television programs to Canadian cities. The worst case is Windsor where only two UHF channels are allocated. It is expected therefore, that there will be many installations of UHF/TV transmitters in the years ahead, limited only by capital funds and government policy. The big users are likely to be educational bodies and second language entertainment channels.

The band 11.7 to 12.7 GHz has been allocated to broadcasting, fixed, and mobile (except aeronautical) users by the International Telecommunication Union. Some preliminary planning has taken place in Europe and North America to decide how best to use this bandwidth for broadcasting. Tentative proposals have been made to allocate some of this band to space satellites for direct broadcasting to cable systems and, perhaps, to augmented home receivers. A system of terrestrial transmitters would suffer limited coverage due to pronounced shadow zones, and severe attenuation caused by rain or snow. Estimates of the capacity of this band in terms of separate programs vary from 10 to 40 depending upon calculations based on protection patterns, population

densities and so on. It is expected that this part of the spectrum will find some use in broadcasting before 1980.

In the next 20 years there is likely to be considerable pressure from other users, for example, national defence, security, transportation, for more of the usable spectrum. It is interesting to note that Japan has declared its policy to abandon eventually the VHF band and to use the UHF band only for television[5]. To quote Dr. Pierce of Bell Labs, "we must look toward a day in which all usable frequencies will be crowded. When that happens, it would seem best to reserve radio transmission for those uses to which it is particularly adapted, such as communications with ships, airplanes, automobiles, and, in general, people on the move". Dr. Pierce may not have included broadcasting in his reference to people on the move. Nevertheless, it is a fact that the AM radio audience uses, mostly, portable receivers; for example, in automobiles. The growth in the use of portable television receivers is expected to be particularly marked in the future as they become smaller, lightweight, more reliable, and as they consume less power.

It is expected that better use will be made of the usable spectrum by better management and by improvements in technology: for example, by reducing the bandwidth in commercial radio telephone applications coupled with a corresponding increase in selectivity of receivers; by reducing the ambient interference level (noise); by better prediction of service areas of broadcast transmitters with computer assisted studies; by time sharing between licensees.

2.4 TEMPORARY LIMITATIONS

2.4.1 Unidirectionalism

The unidirectional nature of broadcasting is generally regarded as one of its fundamental features. This may be so within the terms of a particular definition, but there is nothing fundamental about it, as known to any taxi-driver. If the required rate of feedback communication were 100,000 times less than that of forward transmission (a conservative estimate), 100,000 people could transmit back non-interfering signals in a feedback channel not wider than the broadcasting channel. The feedback power could be kept low by frequent spacing of the feedback-receiving antennae. A similar approach is already used in practice by the mobile telephone system. More sophisticated designs are already on the drawing boards. For example, Sylvania has demonstrated a system called Educast that allows the listener to answer questions. The development of broadcasting with feedback facilities will depend upon the extent to which the demand for this type of service is not satisfied by cable systems.

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[5] ABU Technical Review, No. 3, July 1969.

2.4.2 Transient and Serial Presentation

Broadcasting is often compared with newsprint to contrast the lasting and co-existent (all-parallel) presentation of information in the latter against the transient and serial presentation in the former. While this is certainly true at the present time, it need not remain so. One can name two ways of producing lasting parallel information. The first is to use a hard-copy facsimile-type printer addition to the existing home receiver, with a corresponding modification on the transmitting side. A set of hard-copy pages may then be accumulated at the receiver much faster than it takes to receive a newspaper by mail. Furthermore, only the desired sections of a publication need be printed. This method can be used over a voice-band-width or a TV channel. In the latter case, hard-copy information is received independently of the visual information on the screen; an example of this is the RCA Homefax system. The second approach is to transmit a sequence of different frames to a TV receiver provided with an electronic memory, and a selector which can be set to capture a frame identified by a particular code number. If a sequence of a 1,000 different frames be transmitted at the full-resolution rate of 30 interlaced frames per second, any one frame will be available once in 33 seconds. This gives an average waiting time of 16 seconds in case of random selection, but much less than that with sequential selection. The first few frames may contain a classified index to the content of the sequence. A hard-copy record of any frame can also be obtained at additional expense.

The above two approaches sacrifice movement, as does a newspaper. A compromise is possible where moving presentation is required, but a low spatial resolution can suffice (e.g. cartoon films, dynamic illustrations of mathematical functions or of simple mechanisms in action, etc.). In such a case, a mosaic of say 16 pictures (4×4) may be transmitted. A selector switch on the receiver permits centering and magnifying to the full-screen size of any one picture, thus giving a selection of 16 co-existent moving presentations per standard channel.

2.5 BROADCASTING

There are essentially two services:

(i) AM radio; there is considerable congestion in this part of the spectrum (medium waves) and there is a tendency towards a 'power war' which allows use of smaller receivers with low sensitivity and low cost. The audience uses mostly portable receivers. No dramatic technological changes are foreseen.

(ii) FM radio; there are no particular problems of channel allocations. Of interest is that there has been a reluctance by the public to buy FM sets; this is particularly marked in the remote areas where the CBC has installed low-power FM transmitters. There are transmissions of FM stereo in most large cities. The audiences are small as yet.

A new radio system has been introduced experimentally in the USA called FM Quadrophonics, a four-channel sound system. The system creates, in the home, a new listening environment which will appeal to music enthusiasts. Proponents claim that quadrophonic sound is relatively independent of room acoustics, speaker placement, and listener location. Unfortunately the system requires the equivalent of two stereo FM channels, and it is not expected to become commercially widespread.

3. CABLE SYSTEMS

3.1 BASIC VALUES

The advantages that today's cable systems offer to their subscribers are:

(i) Greater selection of 'off air' TV channels plus music channels plus information services*.

(ii) Better picture quality on the average; freedom from ghosts, less interference between signals, and better signal-to-noise ratio.

A fundamental advantage of a cable system is that it is capable of expansion without using the valuable electromagnetic spectrum of free space.

Hence, cable systems, because they do not propagate Hertzian waves in free space, can coexist without causing interference with one another.

3.2 BASIC LIMITATIONS

(i) The source has a solid connection to all the receivers;

(ii) the cable system requires modification with additional cost to connect additional receivers.

From (i) and (ii) it is clear that cable systems are unlikely to reach all the population of Canada. The satellite-cable system combination is particularly promising to help connect remote townships to national networks.

Also, the cable system cannot satisfy the needs of the mobile audiences,or the family that prefers 'free' television. It is difficult to conceive of broadcasting disappearing, although its role may change.

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* In addition to the diffusion of 'off-air' television and radio programs, cable systems originate their own programs. A typical example is a cable company in Montreal that transmits 35 hours of its own (local) programming per week. This type of service is expected to grow considerably in the years ahead.

3.3 TEMPORARY LIMITATIONS

The cable systems in Canada are physically independent, serving urban areas with a longest path length of 35 miles between source and receivers. With today's equipment it is possible to increase this distance to 100 miles. There is no interconnection between cable systems. The bandwidth carried by the cable systems is 54 - 216 MHz, i.e. 160 MHz. There is no hardware available today to allow the cable systems to be connected into a national network from coast to coast. Nevertheless, it is expected that common carriers will be able to provide facilities with adequate bandwidth before 1980 for a national 'grid' of cable systems if required. The expectation is that space satellites would play an important role in any future national 'grid' of cable systems.

The services supplied by cable systems include television programs, FM stereo programs, and FM radio programs. The number of television channels available is limited by the VHF tuner to channels 2 - 13. Of these, the cable system is unable to use satisfactorily local channels because of inadequate isolation to ambient signals of home receivers. Therefore, local signals are transposed to other channels. Local channels are salvaged by using them for FM radio. Cable system companies would like to use the entire spectrum between 54 and 216 MHz (or even 300 MHz) for distributing television and radio programs. A new type of television receiver (a cable system receiver) would be needed to select channels throughout this band. This receiver would, desirably, include better isolation from ambient rf signals than existing 'off air' receivers. The band 54 to 216 MHz is capable of providing 20 or more channels in a cable system. There is no technical difficulty, but there are no known plans for designing such a receiver.

To take advantage of the FM radio signals available on a cable system, a separate FM stereo receiver and cable connection is required to select from as many as 23 (Victoria) FM stereo channels[6]. The bandwidth of the cable system, 54 - 216 MHz, includes the FM radio services but these are not picked up and fed into the cable system by the cable company except as specified.

The technical quality of the signals delivered to the subscriber is generally below the best broadcast quality but better than typical broadcast reception. However, cable systems are now licensed by CRTC and it is expected that standards of good performance, which have now been specified by DOC, will help to raise the technical quality.

In general, there is no solid connection between the broadcast station and the cable system. The CBC has declined to supply a direct feed of its broadcasts to cable systems, although some private stations have done so. Obviously, there would be a technical quality advantage in making a direct solid connection. There is no technical difficulty.

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[6] Private communication — National Cablevision, Montreal.

3.4 THE 'BROADBAND COMMUNICATIONS NETWORK'

The term 'broadband communications network (BCN)' has been coined by EIA (USA) in a docket to FCC[7]. The essential features of a BCN are that it,

(i) be national in dimensions,

(ii) have a minimum of 300 MHz bandwidth to provide many information services, for home, business and government, such as broadcast video, first class mail, and educational material.

(iii) provide limited return bandwidth for receiving and tabulating specific requests and responses by individual users.

The estimated capital cost is $240 per home connection assuming that 50% of the nation's (USA) homes are connected. No estimate of monthly charges for services is given. In sparsely populated areas where BCN networks are not economically feasible, it is proposed to provide the new services by space satellites.

EIA expects that the BCN system will have a profound effect on 'our way of life in the USA' in the 1980's.

Of significance to broadcasting is EIA's recommendation that there be minimum disruption of present day public communications services. Implicit in this statement is the acknowledgement that broadcasting will have a place alongside the new technologies in the 1980's.

4. HOME TERMINALS

4.1 HOME STORAGE OF AUDIO/VIDEO PROGRAMS

During the next five year period, 1970-75, it will be possible to view television programs on the home TV receiver via a local playback attachment.

The CBS-EVR system offers pre-recorded photographic film cassettes at little more cost than a book or phonograph record. The CBS system is in an advanced state of development, and it is expected to be in use by educational and industrial organizations during 1970. The cost of the playback attachment will be, initially, $1,000 for black and white, and $1,400 for color. The color version is not expected to be available before 1971.

The RCA/VPS (Selectavision) system uses holographic recordings on vinyl tape. It is in an early stage of development, and it is not likely to be available before 1972. It is expected to appeal,

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[7] EIA filing of FCC Docket 18397, Part V.

particularly, to the home market because the recording medium is so robust and the recordings are expected to be as cheap as phonograph records. Prices quoted are $600 for the playback attachment, and two to three dollars for a half-hour color cassette.

Both the CBS and RCA systems are essentially methods of printing, in large quantities, audio/video programs in a suitable form for simple inexpensive playback devices.

Several companies are marketing inexpensive video tape recorders (VTR's) that use magnetic tape as the storage medium. However, there is no compatibility between makes, and there is at present no input or output connections on the home receiver to use them. This deficiency is likely to be remedied by 1972, and the price of a color VTR with home receiver attachment is expected to be around $1,000 at that time: a black and white VTR should cost no more than $500. Magnetic tape cassettes are expected to be in common use by that time. Also, prerecorded cassettes are likely to be available but at an unknown cost. One of the technical difficulties with inexpensive VTR's is that not only are machines incompatible from make to make, but they do not always playback satisfactorily recordings from another machine of the same type. An advantage of the home VTR will be that it can be used to record programs 'off air' for later playback. The home VTR will be capable of recording home-made video programs using an inexpensive vidicon camera. The cost of such a package of VTR plus home receiver attachment plus vidicon camera for color pictures will be much more than an equivalent 8 mm amateur film package for the foreseeable future; also, the technical quality is not likely to be as good during the same time span.

4.2 OTHER HOME TERMINAL DEVICES

Facsimile printers, e.g. the RCA Homefax, have been demonstrated to provide a one-way hard copy of print or data. The RCA system provides an electrostatic printout from information in the television vertical interval. In this case, the technology is developed, and is awaiting a demand.

A facility that is now in operation experimentally in several countries is bi-lingual television. That is, the home viewer has the choice of listening to one of two languages. There would appear to be social and political advantages in such a scheme for national events such as sports. The cost of the home receiver adaptor in one of the systems under trial, in Japan, is less than $100. There would appear to be no technological difficulties in implementing this facility at this time.

4.3 HOME TERMINAL COMPONENTS

4.3.1 Display Devices

Present day display tubes (cathode ray tubes) are expected to show continuing significant but undramatic improvements in terms of brightness, color rendition, stability and general picture quality. Color display tubes with larger scanning angles are expected to be available in 1970, with consequent reduction in depth of the television cabinet.

A great deal of work has been and is being done to perfect various forms of flat television screens. So far commercial success has eluded these efforts, and it is improbable that during the next five years a radically new display device will be commercially viable. The flat display device most likely to be successful is the solid state matrix of light emitters: but this is not expected before 1980.

The use of laser beams to provide large bright two-dimensional color picture displays has been demonstrated in the laboratory. Also, lasers have been suggested for three-dimensional color television displays. There is considerable uncertainty about when these devices might be commercially available in the home, but it is not likely that they will be available before 1990.

4.3.2 Solid State Technology

Today's typical television receiver is still full of vacuum tubes. A recent small and slow introduction of solid state devices and integrated circuits to television receiver circuit design is likely to gather momentum and take over from vacuum tubes entirely by 1975. The improvement in reliability, stability, size, heat dissipation and, eventually, cost will be considerable. Solid state components already have replaced vacuum tubes in other home terminals for example, record-players, AM receivers, the newly developed CBS-EVR player, and new home video tape recorders.

5. THE 'COMMON CARRIER' DISTRIBUTION SYSTEM

Two technological developments are likely to dominate changes in the distribution systems. Firstly, space satellites, and secondly digital signals.

5.1 SPACE SATELLITES

Canada's first space satellite will be in position and working in 1972 to take its place as part of the CBC's program distribution system. Its main advantage is identical and complete coverage for both languages to anywhere in Canada, including the Yukon and North-West Territories. Some 30 ground stations will be built initially and more will be built as money becomes available, with a likelihood that all developing communities will have access to the space satellite by 1980. The first

satellite will use the 4-6 GHz microwave band. Later in the decade it is expected that satellites will be in position to transmit in the 12 GHz band (see 2.3 above) directly to community cable systems and, perhaps, to home receivers.

Plans have been proposed to use the upper part of the UHF band for space satellites to transmit to community antenna systems. However, there is already considerable usage in the USA of this band for terrestrial broadcasting and these plans are unlikely to be adopted.

5.1.1 Intercontinental Distribution

International satellites placed over the Atlantic and Pacific have already been used to connect Canada to broadcast systems in other continents. This type of intercontinental programming is growing rapidly in number of hours per year. The technical quality of the color picture has been improved by the recent development of an all-electronic-systems-converter, that converts the PAL or SECAM system to the Canadian NTSC system. Previous optical converters were of low quality. The need to convert between television systems poses the question 'when is a single internationally accepted standard likely to be adopted?' The answer is probably not in the next 20 years. The reasons are political and economic since so much money is tied up in existing plant and home receivers.

5.2 DIGITAL TECHNIQUES

Today's most important distribution channel for long haul terrestrial TV circuits is the TD2, which cannot pass the high bit rates required for digital TV signals (100 MB/S). New terrestrial distribution systems now under development (e.g. the T5 coaxial system) for commercial use in the late 1970's are being designed to pass digital TV signals. The cost per mile for digital signals is expected to be less than for today's analogue signals through the TD2. Looking farther into the future, millimeter waveguides are expected to provide even cheaper channel cost per mile. Bell Research Labs are assuming in their calculations a two to one reduction in bit rate (to 50 MB/S) by taking advantage of redundancy in the TV signal.

The advantages of digital signals when compared with analogue signals are that they provide the most efficient use of a communications channel in terms of bandwidth and noise; cheaper circuits may be used with minimum maintenance; they provide improved performance in terms of linear distortions of video and audio signals; they may be time multiplexed. The advantages of digital techniques will be applied to space satellites as well as terrestrial communication systems in the same time period.

A method of marrying audio and video signals in distribution systems has been in use in Great Britain for several months. The audio is encoded in PCM binary digital form and inserted into the line sync period of the television waveform. The results of this method of operation are believed to be successful. Similar techniques have been proposed for the Canadian space satellite TV channels. This technique

reduces distribution channel requirements, and hence cost. It also eliminates audio and video delay differences. It is expected that this technique will be in use in the television distribution systems before 1975.

6. THE BROADCASTER — PROGRAM ORIGINATION

Program origination in broadcasting is almost entirely one of 'canned' programs. Approximately 55% of the CBC's TV English network programming is from 16 mm film and 35% from videotape; and 60% of the CBC's French TV network programming is from 16 mm film and 30% from videotape. The other 10% or less in both cases is made up of live programs of sports, news, etc. Thus broadcasting centres can be considered as program factories with the following functions:

(i) to produce 'canned' programs,

(ii) to produce live programs,

(iii) to control program traffic to the transmitters.

The first two functions are concerned with the artistic side of broadcasting; technological developments in this case will be towards improved and smaller electronic pick-up devices, more operational flexibility and more reliable equipment. New technological developments in color cameras are likely to be significant in the next decade. Improved sensitivity and smaller size of color television cameras are expected in the next five years using improved pick-up tubes and improved circuit components and techniques. It is likely that before 1980 a color television camera for portable use will be no larger than a professional 16 mm film camera. In the 1980's solid state pick-up sensors will provide additional performance reliability and robustness.

The reduction in size of the electronic pick-up camera and the availability of small portable professional video recorders will make television production more dynamic and will take production crews outside studios into natural settings. The example of the film industry is a sign of things to come in this respect.

Program traffic control is likely to become increasingly automated to reduce labour costs. This will be due also to the recognition by broadcasting managers that program traffic control is essentially routine work. Past practices of manual control were necessitated by unreliable equipment. Modern equipment is already sufficiently reliable that a considerable measure of automation is possible. Future equipment with IC's and LSI's will be much more reliable. Also, increasing automation will demand the development of cassettes for 'canned' programs. Already cassettes are being used widely for audiotape; and a new cassette has been demonstrated recently for videotape. Cassettes have not been applied to film in broadcasting yet.

The application of digital techniques to audio and video circuits will make possible complete automation of program traffic control. The likelihood is that the common carrier distribution systems will be using digital circuits in the early 1980's and that program origination equipment will not use digital signals until some time later. To pass digital signals requires audio and video equipment with increased bandwidth, and also recorders of increased storage capacity in terms of bits per second.

Today's video tape recorder (VTR) cannot store the vast quantity of information in a digital TV signal (100 MB/S). Considerable research is underway in various laboratories around the world to increase the density of storing digital information. For example, Ampex has achieved 10 MB/sq. inch by laser recording in a magnetic-optical system; this method requires 10 sq. inches per second for 100 MB/S. Today's VTR uses 22½ sq. inches of tape per second. Other techniques having higher density of packing data have been announced by various laboratories. The computer industry has a similar requirement for the storage of vast quantities of digital information, which factor will hasten the development of a suitable storage medium.

It is anticipated that equipment will be available in the early 1980's that will record TV signals in digital forms for less cost than today's VTR. It is likely in this time period that advantage will be taken of redundancy in the TV signal and that the bit rate will be reduced from 100 MB/S by at least 2 to 1 (see 5.2 above).

APPENDIX D

FUTURE TECHNOLOGY ADVANCES AND NEW SYSTEMS CONCEPTS*

CONTENTS

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* Contributed by the Electronic Industries Association of Canada (EIA Land Mobile and Marine Equipment Sub-Committee).

CONTENTS (Cont'd)

ABSTRACT

New Technology and Its Application to Mobile Communications

The first Section in this report reviews a number of the technological trends and developments which will effect mobile and portable two-way radio communications over the next decade and beyond. The impact of integrated circuits on land mobile communications is reviewed with its expected impact on digital communications and portable communications products. The impact of the computer in improving operational value and in improving spectrum utilization is covered. The effective digital signalling and logic and the impact on bandwidths is reviewed. New product developments including the mobile printer, integrated antennas, slow scan television, heterodyne repeaters and vehicular repeaters are reviewed with their impact assessed. Finally, the field of satellite communications is reviewed.

New User Demands for Mobile Communications

The improvement in technology covered in the first section has led to new product and system concepts of value to the users. Some of the more significant developments including record form communications, vehicle location information, vehicles status monitoring, mobile computer access, mobile and portable alarm and signalling, and mobile visual systems are reviewed. The conclusion is that these new system and product developments responding to user requirements will increase spectrum requirements in the future.

Future Technology as an Aid to Spectrum Conservation

A number of proposed concepts to improve spectrum utilization are reviewed. Some of the concepts that are discussed are channel splitting, cellular communications, trunking, share systems, multiplexing, modulation techniques, selective devices, computers for geographic allocation, multi-repeater pickup, and transmitter synchronization. Prospects of these system concepts are reviewed. The general conclusion is that the progress already accomplished in land mobile communications and improved spectrum utilization are reaching the point of diminishing returns. It is predicted that additional spectrum will be required sometime during the next decade since these technological system concepts are not expected to permit significant spectrum conservation beyond that already accomplished.

SUMMARY

Future Technology Advances and New System Concepts in Mobile Communications

1. Impact of Technology

Technology will shape the future and nowhere is this more true than in the field of electronics and communications. For we are now on the brink of a revolution in the manner of communicating man to man,

man to machine and machine to machine. And now the machine is moving into the automobile and will stand ready to receive (and transmit) the words and numbers and pictures which will be necessary for the speed, the accuracy and the efficiency of modern command and control.

The seed for the revolution is the Integrated Circuit (IC), the forerunner of Large Scale Integration (LSI) which will make feasible the manufacture of the peripheral machines, will spawn new inventions and will reduce the cost and improve the performance and reliability of present day equipment.

At this writing the IC is having its impact on mobile communications with the design of new radio equipment employing the devices. IC's are particularly applicable to digital circuits and equipments using digital signalling such as teleprinters and vehicle location and identification devices are making their appearance and will be forerunners of new sub-systems still to come. Indeed, the LSI and breakthroughs in speech processing may well combine to make digital transmission the standard mode for mobile-communications in 20 years or less.

2. Uses, Applications, and Technological Response

Our world is threatened everywhere by startling increases in our crime rate and by the apparent disregard for law and order by an increasingly larger segment of our society. The fruits of modern electronic technology are being used by the criminal in his nefarious schemes and law enforcement agencies must stay ahead if they are to achieve success in their war on crime and insurrection. The answer is faster and more secure and complete mobile and portable communications. The speed, security and accuracy will be enhanced through mobile data transmission and technology will give us the machines such as computers, printers, locators, identifiers, etc., to accomplish this objective. Improvements in portability through smaller size units with lower power drain will take communications from the vehicle to the man on the beat and new receiving stations with automatic voting and vehicular repeaters will sustain communications regardless of location.

The value of human life is steadily increasing and the public is making demands for improved methods to call for help or improve medical treatment in an emergency. Similarly, automatic alarm systems to protect public property are employing radio transmission to maximize security.

The techniques so necessary for human protection and safety are also applicable to the more efficient dispatching of goods and services. Whether it be improved transit or taxicab service or more efficient delivery of fuel or ready-mix concrete, the public will reap the benefits.

Radio paging is another example of the need for timely communications to portable units for people on the move. We now have systems with tone only alerting and tone alerting plus voice message. There is need for acknowledgement of the message and once this has been achieved the full two-way portable message system will follow.

Pollution of the air we breathe and of our water resources is becoming of increasing concern. Our industry will be developing new methods through radio communications to sense, monitor, control and police this threat to our environment.

The electronics industry will respond to these user demands with new products of smaller size, lower power consumption, higher performance and lower cost.

3. Technology and the Spectrum

As technology influences the demand for spectrum, so it must influence its efficient use, allocation and management. In the past pressures for more spectrum were met by channel splitting so that more channels could be contained in a segment of spectrum allocated to mobile service. Technology was at hand in each case to improve equipment performance standards and help combat the higher interference potential of closer spaced channels. In the USA, at the present time, new channels are necessary, but technology, because of the law of diminishing returns, has not reached the point where greater transmitter density can be achieved by further channel splitting. Indeed, there is room for further technological advance to improve the lot of the urban user who suffers interference at current channel spacings.

The objective in efficient use of the spectrum is to enable as many people as possible to use each allocated channel. The wide variety of uses makes it mandatory to use different techniques to maximize utility for each class of service. For example, restriction of coverage area for each transmitter will enable more transmitters to be installed in a given region and thus permit more simultaneous conversations in that region. This is practical to only a limited extent with dispatch systems but has potential for real economies in a mobile telephone system supported by a large wire line plant. Similarly, trunking techniques, while necessary for mobile telephone, are too unwieldy for large command and control systems. For the smaller users the concept of shared facilities is a genuine approach toward maximum channel occupancy.

Utilization of the channels will increase through demand for transfer of more information. Technology in the future will be aimed at increasing efficiency through changes in transmission techniques and redundancy removal in the information transmitted.

New technology will also be directed toward systems concepts that will conserve spectrum and computers will aid in the design, be a component of the system and assist in making the most favourable frequency selection.

4. Technology and the User

The mobile radio user has reaped the benefits of the technology that has given him improved performance, smaller size and weight and greater reliability in his mobile and portable equipment. On the other hand he has had to pay dearly for the changes in equipment due to channel splitting and the tightening of standards necessary to fit the

large numbers of users into the small amount of allocated spectrum. At the same time, through lack of development at an equivalent rate, there were large blocks of spectrum unused.

Should these large blocks of spectrum continue to go unused? Should the land-mobile user be faced with the cost of filters, circulators and still higher equipment standards to fit their increasing numbers into their busy 10% (of spectrum)? Greater use of spectrum will maximize benefits to all and lower costs will stimulate greater use.

Technology for spectrum economy must go hand in hand with management policy, which in realistic time frames permits, indeed encourages, maximum use of this valuable natural resource.

1. NEW TECHNOLOGY AND ITS APPLICATION TO MOBILE COMMUNICATIONS

Introduction

Technology influences the growth of mobile communications by:—

1. Development of equipment and systems to satisfy user needs.

2. Reducing cost factors making the products available to larger numbers of users.

3. Enhancing spectrum utilization so that more can use the spectrum.

It is the vitality of the electronics industry participating in the free enterprise system, through the stimulus of competition and the innovation and dedication of industry members that the benefits of mobile communications are made available to increased numbers of Canadians.

Generally speaking, there is an elapsed period of about ten years between the invention of a new basic device until the device finds application in a product at volume production.

Predicting the course of future technology is a risky venture, however, by looking at the recent past and examining some basic technology still in the laboratory, one can conjure up a vision on what is in store for us during the next ten or twenty years.

Some present day technology already has the potential to vastly increase the efficiency of mobile communications and some equipments available are described in this section. The impetus of future technology will be directed toward making existing developments economically viable in the mobile radio environment.

Future technology will improve the operational value of mobile and portable radios and create an accelerating requirement for more channels.

1.1 INTEGRATED CIRCUITS

By IEEE definition, an integrated circuit is "a combination of interconnected circuit elements inseparably associated on or within a continuous substrate". While the term in general applies to assemblies of circuit elements interconnected using thick film, thin film or multi-chip technology, which more or less complies with the definition, present date usage usually refers to the monolithic IC.

This is a combination of a many electrical elements, such as transistors, diodes, resistors, capacitors, etc. and their interconnections which are deposited on a small silicon chip using oxide masking techniques. Like its parent, the silicon transistor, the IC has the advantage of small size and low power consumption. Monolithic IC's have reached a stage of development where reliabilities of a high order are realized and the large scale batch processing techniques used makes the devices economically suitable for large volume usage.

Monolithic IC's have found most usage in digital circuits as found in computers, control systems and in military and space electronics. Their application to linear or analogue circuitry, such as is found in mobile communications equipment, has been slower due to the functional diversity found there and the difficulty in achieving competitive costs in acceptable tolerances and a suitable substitute for inductors. IC's have found limited usage in IF and AF amplifiers, particularly in personal receivers where the space factor is important. During the next five years there will be a great upsurge in the use of IC's in mobile communications equipment. This will follow, since in this period the device will reach maturity with achievement of both higher reliability and lower circuit costs to be expected over assemblies of discrete components. Also during the next five years, there will be an acceleration in the use of digital circuitry in mobile communications and IC's even now are commonplace in such circuits.

An advantage of the batch process used in the manufacture of IC's is that more and more active elements can be added to form more complex circuitry or even a multitude of circuit functions without large escalation in cost. Thus we have MSI (medium scale integration) with the equivalent of about 25 IC's on one silicon chip or LSI (large scale integration) with over 100 functional elements and perhaps as many as 2,000 junctions.

As with IC's the LSI will find first usage in the computer industry for small, low cost memory shift registers and logic circuitry. Development of these devices will continue in this market for probably the next ten years, at which time LSI applications in the mobile communications field will receive attention.

An obvious target for the LSI is the personal communications receiver or transceiver which ultimately will consist of a single chip as the active circuit element. In the meantime, there will be a transitional period when interconnection of discrete transistors, single function IC's and hybrid sub-assemblies will be effected using printed wiring followed by thick and thin film techniques.

1.2 COMPUTERS

Third generation machines, using integrated circuit technology, have grown in size and capability during the sixties. Reductions in costs of the basic devices used in memory and logic circuitry have given birth to the small computer and they are being applied now to a large number of on-line requirements. Mass production during the next five years and large scale integration by the end of the decade will result in a continuing decrease in costs and hence, more widespread usage.

Perhaps the most valuable application of the computer in mobile communications is in the public safety services where the command and control function will be more efficiently handled.

Combined with a vehicle location and status reporting system, the computer will take over and perform more efficiently a major share of the dispatcher's job. First of all, a continuously updated status of available equipment and personnel is maintained and can be displayed in various forms. Secondly, the dispatcher will interact with the computer by means of previously established routines to select the correct response to the situation at hand. Finally, it will aid in carrying out the mission by selecting the proper force units and communicating the necessary information to them.

In the business radio service, the same benefits will occur in dispatch operators. In fact, some routine dispatching may be eliminated altogether. The computer could accept a command by punch-card to deliver a product to a certain address. The computer would locate the nearest vehicle to the address, check its inventory and dispatch the driver via teleprinter. Inventory control and invoicing would be a logical by-product of the operation.

Mobile Access to Central Files

It is now technically feasible to use the radio channel between a vehicle and its headquarters for direct access from the vehicle to the data stored in the memory files of a central computer. An inquiry on a key-board in the vehicle is translated by a suitable encoder into signals suitable for transmission over the radio link. At the dispatch centre the received signals are routed automatically to the computer, which processes the incoming message and searches the memory stores for the desired information. The information or other suitably composed replay is automatically encoded and fed to the base station for transmission to the vehicle when the channel is free. At the vehicle the receiver feeds the signal to a decoder for translation into a form suitable for driving a mobile teleprinter or other display device, for example, a cathode-ray tube.

This technique is in the experimental stage. Though specific equipment is not yet commercially available, it is likely to become available in a short time, provided that the DOC will authorize this usage of radio channels and that the demand-vs-cost relationship can be resolved. The critical problem here is the ability to gain the use of a channel for the duration of an inquiry without disruption of the

message by other mobiles. Ultimately, a dedicated channel will be required due to projected explosion in usage.

With reduced costs, computers with large memory banks and less arithmetic capability will become available and will enable a central file of vehicle registrations, maps, status information, etc., which will become available to the mobile operator by direct access. Data sets in the vehicle will give way to small mobile type computers, thus decentralizing some of the functions and providing more efficient communications with the central computer. This equipment will be in general use by 1990.

According to some researchers, the ultimate system to provide access from a moving vehicle to a central computer or a data store will not require a vehicular keyboard. Rather, direct voice input, via radio link, to a speech recognition device, will, for example, permit a police officer to request a vehicle license check during a hazardous, high-speed chase, without taking his eyes off the road or his hands off the steering wheel. The speech recognition apparatus converts the inquiry message to computer language. The computer reply over the radio link could be either in digital form directed to the vehicle's mobile teleprinter, or in the form of synthetic speech for output over the loudspeaker of the mobile radio.

Most of the work on machine recognition of spoken messages is being done by the major telephone laboratories, the computer manufacturers, and some of the universities. A part of this research is sponsored by government, mainly for military purposes. Some success has been claimed in that a machine has been able to recognize a few words. However, much more remains to be done. Besides the basic requirement for a reasonably large vocabulary, the machine must be capable of handling inflectional variations, individual differences in voice quality and pitch, regional differences, foreign accents, etc. These problems appear to be difficult ones as attested to by the slow rate of progress over a period of 17 years. Practical equipment is probably well beyond five years away. Computer access by voice, using a concise, simple vocabulary, may be possible within ten years.

1.3 DIGITAL SIGNALLING AND LOGIC

Data signals are inherently digital in form, consisting of time separated electrical pulses, and therefore do not require any conversion process for transmission over a digital system. Digital transmission has the advantage that it can be made less susceptible to noise in the transmission path by coding techniques and regeneration of clean pulses before decoding. Digital transmission in the land-mobile field has, until now, been limited to selective call systems, however, transmission of data to and from mobile units is now coming into more general use in vehicle location and mobile teleprinter systems, as examples. These systems have become economically viable, first because of the reduced cost and improvement in reliability of the silicon transistor during the past five years, as well as the development of the monolithic integrated circuit.

Further development in semiconductors, particularly in the area of large scale integration, will yield even lower cost digital hardware so that accelerated usage can be anticipated during the 1970's.

Digital and analogue technology will proceed in parallel in the '70's as conversion of the analogue voice signal for digital transmission over radio is as yet impractical due to the bandwidth requirements (as much as 16 times the bandwidth of the voice spectrum). Development of new techniques for efficiently digitizing analogue signals by removing redundant content will surely reach maturity in the 80's so that the advantages of digital transmission can be obtained for all signals.

Economics may at first dictate the use of shared channels for the transmission of digital and analogue information. As time goes on, the utility of digital transmission of data will demand a dedicated channel.

Digital transmission of an analogue signal (e.g. voice) is usually by Pulse Code Modulator (PCM). The PCM signal is generated by sampling the amplitude of the original signal at a high enough rate that the character of the signal can be faithfully reproduced. This indicates a sampling rate which is twice the highest frequency in the analogue signal. The numerical value of the sample is converted to a binary number which is then represented by a sequence of 1 or 0 pulses (bits). For a high quality speech reproduction, six to eight bits are required per sample. The bandwidth required in the transmission medium is twice the above numbers times the highest frequency to be transmitted.

Fortunately, pulse code modulation signals lend themselves to redundancy removal or bandwidth reduction techniques.

Redundancy removal is based on the prediction that the waveform of the signal will follow a pattern which depends upon its recent history. Removal of redundancy while the signal is in its analogue form is complicated but the PCM signal may be processed in simple logic circuitry to remove unessential information.

Present day technology permits reduction of PCM bandwidth requirements by a factor of about five for voice transmission. This is still three times as large as required for unprocessed analogue transmission. Even with this bandwidth the naturalness of the voice suffers somewhat. Therefore, significant trade-offs must be considered in the form of loss of voice quality and added equipment cost and complexity if further bandwidth reduction is to be achieved.

There are several schemes for accomplishing bandwidth reduction, including Waveform approximation, Delta modulation, Extrema Sampling, Vocoders and Electronic Speech recognition. While the latter system eliminates the individual's voice characteristics, it has the greatest potential for reduction of bandwidth. It is possible that it will find usage in police command and control systems as it has the advantage that privacy of transmission is inherent.

The next few years will see increasing application of digital circuitry to mobile communications. This usage will provide the spur to develop suitable analogue/digital interfaces so that direct man-to-machine communications will be a reality by 1990.

1.4 SYNTHESIZERS

Frequency synthesizers have already been developed to generate in a small package the large number of frequencies required in tactical military equipment, and more recently, in air-to-ground communications. Until now the technology has not been developed to the point where economical application to land mobile service can be realized. This is despite the fact that the frequency generation devices in a multi-channel mobile radio unit may represent a substantial percentage (30% in some cases) of the total cost of the radio.

More efficient usage of the land-mobile facility now demands that each mobile unit be capable of operation on a larger number of frequencies. Public safety systems such as police and fire networks now require as many as 12 channels for efficient command and control in a large metropolitan area. Urban transportation systems also, because of the large number of vehicles involved, will require multi-channel capability in each mobile unit. Previously, only mobile telephone systems required so many channels in one radio and expansion of this service and incorporation of the cell concept during the next ten to twenty years is going to raise demands on the mobile unit which cannot be met with current techniques.

The answer of course is frequency synthesization and refinements in technology will enable the appearance of radios using this concept within the next ten years and general utilization in twenty years.

1.5 MOBILE PRINTER

Modern basic technologies have teamed up to produce compact pager-printers for vehicular use. Only the availability of integrated circuits makes these printers practical since small size, high reliability, resistance to shock and vibration, and low current drain are essential to mobile service. Some new developments have led to simplification of the mechanical requirements to reproduce 100 wpm in a vehicle. One design makes use of piezo-electric crystals as printout hammers instead of noisy, power consuming, solenoid-actuated hammers which typifies the more common office teleprinter. Mechanical parts are limited to the paper feed mechanism and the platen.

Pressure sensitive paper is passed up and in front of the platen which is a roller with a raised helical ridge turning at a constant speed. There is no stopping or starting of the paper and no carriage return to add mechanical complexity. Six hammers are indepently and momentarily driven forward and their canted striking bars mark the paper with a dot where the bar and the helical ridge are coincident. Each line has 36 characters, each formed by a 5×7 dot matrix. All of the

top rows of dots in all the characters are printed before the second row is printed. This is accomplished by driving the six hammers with six parallel pulse trains. One row of dots is made for each revolution of the helix. The system has the advantage that noise impulses on the transmission channel will have little influence on the message error rate as the characters are still readable even with a whole row of dots corrupted by a noise burst.

The mobile teleprinter is now ready for application to the mobile services. There are some system design considerations which must be taken into account, such as the desirability of a dedicated communications channel, however, the hardware is ready now for those who have the need. It will be in widespread use by 1975 due to cost reductions from larger scale production.

1.6 INTEGRATED ANTENNAS

An integrated antenna or active antenna is one in which an active element such as a diode or transistor is integrated with the radiating element or elements. The use of passive devices, such as capacitors, inductors, etc., for impedance matching electrically small antennas is well established, however, the bandwidth that results is usually less than one percent. When the size of the antenna is one-tenth wavelength or less, the Q is very high, the bandwidth extremely narrow, and impedance matching requires special approaches.

By using a transistor placed in the antenna structure, the current distribution can be magnified to the point where the resistive component will match the transmission line over a broad bandwidth. The practicability of small antennas using transistors has been established.* They have been mentioned here, not because of any known current application to mobile communications, but because the concept opens up new horizons in antenna research. With new devices becoming available, it is reasonable to expect that antenna arrays, using integrated elements, may find application in communications where antenna size is a critical factor.

1.7 SLOW SCAN TV

An outgrowth of Television technology is a means of transmission of pictorial information over channels much narrower than the 6 MHz standard NTSC bandwidth. These slow scan techniques are possible only if the scenes to be transmitted do not contain objects in rapid motion or if some blurring of objects in motion can be tolerated.

Two approaches are possible. An adapter can be used to convert a standard video signal from a camera to a narrow-band signal. Alternatively, special camera circuits can generate the required narrow-band signals directly.

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* Subminiature Integrated Antennas
Edwin M. Turner
1967 Conference on Vehicular Technology, New York.

The required bandwidth of the transmission is a direct function of both the number of frames to be transmitted per second and the desired resolution of the picture. The signal can be made to fit a 3 kHz voice channel and thus can be transmitted over two-way radio.

A matching receiving device is required to convert the signals to a form suitable for display on the monitor.

The technology for slow scan TV is already well established. Further work is undoubtedly required before costs will be low enough to encourage large scale usage. It is anticipated that first applications of these systems in the mobile radio field will be by law enforcement agencies.

1.8 REPEATERS

1.8.1 Heterodyne Repeaters

This type of repeater enables a signal to be received and retransmitted without demodulation and remodulation at audio frequencies. Stations using this technique enable signals from mobile units to be processed through several repeaters in a long system without audio response and distortion degradation which would make the system impractical with ordinary remodulating repeaters.

While the scheme has found application in Europe*, it has been more common practice in this country to use a trunk facility for interconnecting mobile repeaters in a linear system such as a pipeline or railway.

The heterodyne repeater has the advantages of economy and spectrum conservation as fewer channels will be required.

Introduction of the system in Canada may be a means to combat frequency congestion in some areas where land mobile channels are used to interconnect base-repeaters.

1.8.2 One-Frequency Repeater†

Another development of some interest is the one-frequency repeater. Various schemes have been proposed and tested which amplify an incoming

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* Narrow band FM RF repeater for mobile radio communications.

  By Enrico Pezzini and Gianni Lovisolo,
  1966 IEEE Vehicular Conference, Montreal.

† For additional information see paper — "Common Frequency Radio Relay "Common Frequency Radio Relaying"

  By: J.G. Churcher,
  1967 IEEE Conference on Vehicular Technology, New York.

signal and simultaneously retransmit it on the same frequency. Some use directional antennas to provide the necessary output-to-input isolation — others use elaborate balancing or time delay techniques. In its present forms, the one-frequency repeater is unlikely to revolutionize the industry, but it will probably continue to be used for special application.

1.8.3 Vehicular Repeaters

These are arranged so that a mobile station can automatically retransmit signals between low-power portable radio units, carried by men on foot, and their associated base stations.

Basically the mobile station, when used for repeater purposes, must be designed so as to be activated only by the presence of a continuous tone, the absence of which shall deactivate the transmitter. Alternately, the mobile may be equipped with a switch, which will place it in the repeater mode, and a three minute time-out-timer. If this design method is used, the continuous tone device is not required.

There are a number of equipment configurations which can be applied to vehicular repeater systems. Each of these concepts brings all the interference problems of a repeater site into the vehicle, and each requires significant system and operational planning to implement effectively.

The selection of system frequencies must be made with due regard to receiver desensitization by the transmitter frequency and the constraints placed upon the use of antenna isolation devices by the physical size of the vehicle. The use of separate unity gain antennas, one roof-mounted and the other trunk-mounted, will provide approximately 20 dB isolation, and will require a minimum of 4 MHz separation between transmit and receive frequencies for a typical repeater having a 30-watt transmitter and a 0.5 μV receiver. This assumes state-of-the-art equipment having excellent desensitization and spurious characteristics. Each system will require analysis of all factors involved to assure optimum repeater performance.

Modern, transistorized equipments are usually designed such that the power supply operates only during the period that the transmitter is keyed and the receiver is muted. Repeater operation requires that both be active at the same time, and consideration must be given to protecting the receiver from noise generated by the transmitter power supply's multivibrator circuit. This can be accomplished by filtering, isolation, a combination of the two, or by the use of a solid-state transmitter requiring no power supply.

Since the principal purpose of these systems is to extend the range of personal portable radios, particularly within buildings, the propagation characteristics of the various frequency bands with respect to portable radio performance is another factor to be weighed. In this connection it has generally been found that RF penetration of structures is enhanced by the use of frequencies above 150 MHz and especially above 450 MHz. This choice is further strengthened by the relative

inefficiency of portable radio antennas at the lower frequencies. The use of low-band frequencies for the portable to mobile link of a vehicular repeater system is therefore generally counter-productive.

A major operational concern becomes evident when consideration is given to multiple vehicular repeaters in the same system. A portable transmission is likely to activate more than one repeater with the resultant simultaneous multiple transmissions causing heterodyning in the base station receiver, which renders the signal unintelligible. One solution would be to code each portable radio discretely to each repeater, which results in a portable radio being used only with a particular vehicle, a rather inflexible method of assignment. Furthermore, if either the repeater or the portable radio requires service, both will be useless unless the addressing code can be readily changed. Alternately, operational procedures to assure that only one vehicular repeater is active in a particular area appear to offer the simplest, though not foolproof, solution.

We have not attempted to define the performance characteristics of vehicular repeaters, or to discuss their relative merits as compared with alternative methods of providing portable communications, such as fixed satellite receiver selection systems. The selection of each system is based on the trade-off between such factors as area that must be covered, number of men equipped, one-man or two-man cars, etc.

Several tests of vehicular repeaters have shown that satisfactory results can be expected. The results of these tests demonstrated the technical feasibility of the vehicular repeater approach. The work now being conducted is directed toward further refinement in systems design and the development of data to permit simpler implementation of vehicular repeater systems in actual user situations.

1.9 SATELLITES

In any discussion on future communication, satellites are inevitably included. It is technically possible to have a radio link between a land mobile station and a satellite on the mobile frequency bands. It may not require an extremely elaborate antenna at the mobile station to accomplish this, either. The US Coast Guard has conducted tests in the 160 MHz band from a satellite to ships with good results. But before everyone rushes to arrange for a satellite mobile repeater station, consider some of the factors involved. First, it must be noted that when you choose a frequency to be used in a satellite, that frequency cannot be used for anything else in almost half the world, assuming a synchronous satellite and relatively wide beam antennas. Clearly, the number of users would be limited in the land mobile frequency bands. A very narrow-beam antenna might restrict coverage to a city-size area and alter this picture somewhat. Then, too, how many land mobile users require the nation-wide coverage that a satellite station will give? Only a few governmental users first come to mind. Since satellites and their launchings are extremely expensive, common carrier satellites with many channels of multiplex are most likely to be seen in the future.

In the land mobile area, satellites will probably be most useful in providing long distance point-to-point links for widely spaced base stations and for wide area coverage of ships, aircraft, and land vehicles under disaster conditions.*

2. NEW USER DEMANDS FOR MOBILE COMMUNICATIONS

Introduction

The phenomenal growth of the land mobile services in recent times has been as a result of the increased dependence of our society on mobility and its attendant communications requirements. This growing mobility and portability in the supplying of goods and services to the public has enhanced public safety and has contributed directly to more timely and economical provision of most, if not all types of goods and services. Whether it be a need for law enforcement, improved transit operation, delivery of fuel or ready-mix concrete, the public benefits when these goods and services are provided in a timely and economical manner.

Effective mobile and portable systems are, however, largely dependent on radio communications in order to direct and control field personnel and equipment. This dependence on radio communications in many, if not most instances, stems from the intrinsic high cost of providing a timely mobile service in response to a public need. This high cost can be offset or reduced by application of effective radio communications.

Although there has been dramatic growth in the application of mobile and portable communications, present day systems fall far short of the total benefits that can be provided in the future by the application of newly available and future communications technology. That new communications technology will have major applications in providing more efficient goods and services is not surprising in this era of information explosion. Data systems, information systems, computer and communications technology are all combining to produce this era, and their effects on more efficient and effective mobile services is just beginning to be appraised. That the impact of these systems and technology will be significant can be appreciated when it is recognized that the bulk of today's mobile communications is limited to voice communications between persons. This level of communications capability, although acceptable by former standards, is not adequate now or in the future.

The need for sophistication in both communications form and content is as great, if not greater, in providing future mobile communications as in non-mobile communications. The question is not IF there

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* From a paper by Daniel K. Clark and Leonard G. Schneller "Innovations and New Concepts in Mobile Communications" presented at IEC Toronto, October 1969.

is a need but rather HOW extensive is the need and what new radio spectrum will be needed to avoid stagnation at todays level of mobile communications.

While it does not appear possible to quantify the impact of new information systems and techniques, it is helpful to dimension the foreseeable needs and relate these to known technological possibilities. Improved mobile communications derive from augmentation of present day systems, i.e. extensions of present day systems using new information systems and/or technology or a combination of both.

Items of information which already have been identified as having general utility to mobile systems include:

- Record-form communications
- Vehicle location information
- Vehicle status monitoring
- Mobile computer access
- Mobile and portable alarm and signalling
- Mobile visual systems.

Each of these imply additional communication capacity and a corresponding increase in radio spectrum requirements. Also, each of these items are of a generic nature and are thus applicable in varying degrees to all the major categories of land mobile communications usage. It is not unrealistic to expect each of these to be implemented and in use on a widespread basis in the next decade.

Added to these are the many unsolved mobile communications problems. Examples of these are radio aids for the distressed motorist, emergency medical monitoring highway route and guidance radio information systems, and air and water pollution, monitoring, and policing. As solutions to these requirements are found and implemented, a further growth in spectrum usage must be planned for,if the benefits of these solutions are to be realized by the public.

The effect of more sophisticated and more extensive mobile communications on future spectrum requirements can easily be many times greater than that required by present day voice systems. As solutions are found to newly evolving mobile communications requirements, a significant growth can be expected to occur in the number of vehicles and persons equipped with radio communication devices. This growth can easily be expected to be several times greater than the level existing today.

The electronics industry meets changing needs with a continuing expansion of new ideas, new devices, new ways of generating information, and new ways of transmitting information.

2.1 PERSONAL COMMUNICATIONS

In recent years, the trend of communications for the man in motion has been toward lightweight portable radios in addition to the more conventional vehicular-powered sets. Examples of such demands have been the personal portables used by airport personnel, by the policeman on the beat, and in industrial internal communications; e.g. manufacturing plant, oil refineries, etc. The essence of the trend is the desire to communicate with an individual — not vehicle.

There is no doubt that the new technology has led to the creation of these applications through increased reliability, improved performance, lower power consumption and reduced size and weight.

Personal communications is a classic example of the growth of operational use, with the concomitant need for more spectrum assigned, resulting from technological advances. The sharp growth in personal radio communications is fundamentally due to improved products — lighter weight, smaller size, higher RF power, increased battery life, and increased flexibility of use — rather than the operational needs which have existed for some time.

Two of the more advanced concepts of personal radio communication will be discussed.

Helmet Radios

The development of the transistor, followed by miniature and micro-miniature techniques for the construction of electronic circuits, led to continual decrease in the size and weight of two-way radio sets. Then with the advent of military quality integrated circuits, it became practical to design a receiver or even an entire transceiver (combination transmitter-receiver that uses some of the same circuits for transmission as for reception) to fit inside of or clip onto a soldier's helmet. The US Signal Corps and other services have acquired several versions of helmet radio, including some in which only the antenna, microphone, and earphones are attached to the helmet, and the radio proper, plus battery pack, are carried in a shirt or jacket pocket. The same approaches are applicable to helmet radios for police, construction workers, etc.

Coverage afforded by miniature transmitters of this type is limited by the configuration and position of the antenna and by the energy capacity of the battery pack held within the weight constraints applicable to portable service.

Within the past five years there have been tremendous changes in the semi-conductor industry. The rapid growth of new devices and the development and growth of the integrated circuit (IC) has made helmet radios a realizable item within the present state-of-the-art.

Within the next five years, using integrated circuits on a medium or large scale integration combined with hybrid micro-electronics, we certainly will be able to build helmet radios with power outputs equal to today's hand-held portable units. We also feel that a break-through

in battery technology will enable us to build smaller and smaller units in the future.

Wrist Radios

The completely self-contained two-way radio, small and light enough to wear comfortably on the wrist, is not here yet and probably will not be for quite a long time, unless one is willing to accept transmitter and audio output powers too small and battery life too short to be practical.

On the other hand, the integrated circuits and microminiature techniques that make the helmet radio possible, as discussed in the previous section, also improve the feasibility of a wrist receiver. The receiver could be complete, including a tiny loudspeaker, but the battery pack would probably have to be carried elsewhere on the person. It is doubtful, however, that the loudspeaker would be useful or necessary. Its audio output would necessarily be low and, in a noisy environment, would require the wearer to hold it up to the ear. This requirement would be a handicap to a person who needs both hands for other tasks. Thus a better approach would provide a lapel speaker or an ear piece connected by wires concealed under the shirt sleeve, or woven into the fabric, to the wrist unit. A further refinement would be a wireless, electromagnetic, coupling of the receiver IF output to a demodulator built into the lapel speaker or earpiece.

A simple version of a wrist receiver (less battery and loudspeaker) may become feasible within five to ten years. A complete two-way unit, including a low-power transmitter, will take several years more.

For further information on personal communications prospects for the future, see the paper by F.R. Eldridge "Concepts for Improving Land Mobile Radio Communications" — published in the report by Eugene V. Rostow, June 1969.

2.2 VEHICLE IDENTIFICATION

Vehicles in a mobile radio network are now identified by voice transmission from the mobile operator. This method will be too slow and inefficient in the future when digital transmission to and from the vehicle will be the order of the day. Vehicle identification by automatic transmission of a coded signal with each transaction will be inherent in the future systems to save air time, to acknowledge a centralized polling signal, to identify source of an alarm signal without alerting criminals, and for record purposes when vehicle data is stored at the central station.

The vehicle identification system will be used by the mobile operator when he wishes to contact his dispatcher. By pressing a button the vehicle identification is transmitted and when received at the base is entered into a display and acknowledgement transmitted. A number of such calls can be entered in order so they can be dealt with in turn by the dispatcher.

If a bus driver is being attacked by a hoodlum, he can trigger an alarm by means of a foot switch which sends a coded alarm, identification and possibly vehicle location to the appropriate authorities.

While vehicle identification could be used as a separate technique to maximize channel efficiency, it is likely that it will be applied as part of a more comprehensive digital system involving status and location information. Either way the problem is not a complex one technically and only the cost factor has limited widespread application. This factor will be overcome in the early 70's with integrated circuit mobile devices.

2.3 VEHICLE STATUS MONITORING

Efficient dispatching of mobile forces requires up-to-the-minute knowledge of the status of each unit of the force. Is the driver in or out of the vehicle? Is the operator on an assignment? What is its priority or is it available for reassignment? If such information must be extracted by voice communication, then not only is spectrum use wasted, but delays are incurred due to difficulty in maintaining status information current.

The ultimate in status monitoring would be continuous data on the activity of every mobile. Such accuracy or speed is not required in most systems so that a means where mobile units are automatically polled when no commands or calls are in progress would normally be satisfactory.

An automatic system will still require a certain discipline on the part of the mobile operator who must enter his status into an encoding device whenever a change takes place. Status monitoring would usually be incorporated with a vehicle location system so that location information would be transmitted from the vehicle with the status.

We already have the basic technology to provide more modern dispatch equipment yet voice procedures and dispatching techniques in many cases are the same as in use 20 years ago. The limitation in application of the new technology was that it was changing so rapidly that users were reluctant to commit large sums to modernization when they had reason to believe the equipment would be obsolete by the time it was in operation. The early 70's will see crystallization of the techniques and widespread application. Technology will be aimed at co-ordination of the hardware elements on a systems basis and reduction of costs of such elements. Computer oriented systems programmed to allow for future expansion will be in demand.

2.4 VEHICLE LOCATION INFORMATION

Vehicle Location Technical Background

The general problem of vehicle location is one of determining position in a two-dimensional environment, and communicating this position to an observer. It is desirable to accomplish this automatically,

with no human intervention required. The location system must have a reference system and some means of measuring or otherwise determining co-ordinates with respect to the reference. In addition to determining position, the system must be able to communicate this information to a central point (or points, depending on operational requirements) and to identify the individual vehicle involved.

(a) Co-ordinate Systems for Specifying Location

There are a number of means of specifying positions in a plane. All are depending on knowledge of appropriate angles or distances which must be measured. Six possible reference systems are listed below with short discussion. The first two are commonly employed by man for specifying locations. It is likely that any location system using a reference system other than the first two, will have to convert to one of the first two at the final output to a human operator (to a dispatcher for example).

The possible reference systems are:

(i) Cartesian Coordinates (x, y or rectangular coordinates)

Location is specified by two distances along mutually perpendicular axes. One common reference point is required. This is the most "natural" system for a human operator and is compatible with cities having rectangularly laid out street systems.

(ii) Polar Coordinates

One angle and one distance are specified from a single reference. This is a "natural" system in that man commonly uses it for navigation (with compass). It is also the reference system of the usual radar transponder system.

(iii) Triangulation

Three reference points are required with angles to or from the target being measured. Two angles may be sufficient if the vehicle travel is restricted so that it does not approach the line connecting two reference points. This system is used in radio direction finding (RDF) systems.

(iv) Measurement of Three Distances

The distances to three reference points are measured. As with triangulation above, only two are required if vehicle travel is restricted. This locates the vehicle at the intersection of two (three) circles. The locus of the vehicle's travel, if one distance is held constant, will be circular. This type of location information is obtained by taking two (three) measurements with an aircraft type of distance measuring equipment (DME).

(v) Measurement of Two Differential Distances

Two measurements are made of the difference in path length to three reference points. Location of the vehicle occurs at the intersection of two hyperbolas. The locus of travel for one constant path difference is hyperbolic. Loran type systems employ this reference system.

(vi) Measurement of Two Differential Angles

Two measurements of the difference in angles to three reference points are made.

(b) Location Determing Techniques

There are three basic techniques available to determine position in any reference system. Probably the most useful technique for a vehicle location system is that of *direct measurement* of the appropriate angles or distances using radar-like techniques. The other possibilities are establishment of a *coded environment* and finally, the use of indirect or *derivative measurement*. These techniques are discussed individually below:

(i) Direct Measurements

By transmitting suitable signals between a vehicle and one or more reference points, it is possible to measure position directly. The measurements consist of a set of angles and/or distances as previously described above.

Two types of signals are available. One, electromagnetic radiation, includes a broad spectrum from commonly used radio frequencies through infra-red, visual light, and ultraviolet frequencies. The other possibility is sound waves, both sonic and ultrasonic.

Directional antennas are used to measure angles. Distances are obtained by measuring the time required for a wave to propagate over the desired paths. This is readily translated into a distance measurement since the velocity of propagation is relatively constant.

While sound has a certain advantage over radio for this application in that its velocity is much smaller and the need for timing accuracy is much less, it has an out-weighing disadvantage in that sound is attenuated much more rapidly.

For the latter reason, it appears that radio will be the principal signal to be used in direct measurement systems except possibly over short distances. Of course, the radio frequency spectrum is large and different frequencies have considerably different propagation characteristics. The choice of radio frequencies is further complicated by licensing.

(ii) Coded Environment

The coded environment technique is actually the means that people use most commonly to determine location. This is nothing more than noting prominent landmarks, street numbers, and signs, or any other cues which are a fixed part of our environment. We then relate the cue to our memory or reference system to fix our position. The significant point is that our environment is permanently marked or coded with the required cues. Society has gone to considerable expense to establish a street number system and directional signs in cities and on roads. Without these, one would be hopelessly lost in unfamiliar areas.

Unfortunately, electronic devices cannot "read" the visual cues established for man. It is possible, however, to establish an artificial "environment" which would contain radio cues or perhaps some other type of cue which might be read by a suitable device.

A straightforward application of this technique is the so-called Electronic Signpost System.

The principal problem of this system is not technical, but rather, the cost of implementation, especially over large areas.

(iii) Derivative Measurement

Missiles and nuclear submarines determine location through a system known as inertial guidance. Instead of directly measuring position, this type of system measures changes in position (velocity or acceleration) and integrates these to derive location information. This is analogous to using a compass in navigation. One keeps track of the distance travelled in each direction taken. Knowing the starting point, it is a simple matter to calculate position at any point along the route. Such a system in a vehicle could be implemented through integration of compass and odometer readings.

The principal technical problem in this type of system is the accumulation of errors in the integration process and the attendant need to correct these errors in each vehicle.

(c) Possible System Approaches

A few system types are mentioned briefly here to show the wide variety of systems which could meet the requirements for a vehicle location system.

In particular, for the sake of brevity only, two direct measurement approaches are described. There are quite a few possibilities. A common question in this type of system is "How much use can be made of the existing car radio to avoid the expense of a second installation?". The second major problem area in direct measurement systems is one of multi-path propagation and, possibly, poor urban coverage.

(i) Radar Transponder System

In this system, a directional antenna array would be located at one or more fixed reference points. Angular information would be obtained by rotating the antenna pattern. To obtain sufficient precision, a nulling technique employing two slightly offset antennas or electronically switched elements would be required. Distance information would be obtained from a transponder in the target vehicle by measuring the time for an interrogation from the fixed site to be answered by the vehicle. Through the use of phase correlation measurements, the transponder function might be provided by the normal two-way FM radio in the vehicle, plus a few additional circuits.

Advantages

Advantages are:

1. A minimum of fixed reference sites are required, possible only one if adequate coverage can be obtained.
2. The directional antenna can also provide better voice coverage if a compatible FM transponder is used.
3. A "natural" polar co-ordinate reference system results which will not require translation to another system.

Problem Areas

Possible problem areas are:

1. Both bearing (angular) and distance measurements can be affected by multipath propagation. The magnitude of this problem is not known and would be a subject for study.
2. A compatible FM transponder may not provide sufficient accuracy. In this case a unique transmitter and receiver would be required in the vehicle and a special wideband frequency assignment would be required.

(ii) Hyperbolic System

Three reference points with receivers would be established to make comparative measurements of the time delay resulting in a signal transmitted by the target vehicle. If a conventional narrow-band FM transmitter can be used for the vehicle signal, no new transmitters are required.

Advantages

Advantages are:

1. Potentially minimum cost vehicle-mounted unit.
2. No new base station transmitters.

Problem Areas

Possible problem areas are:

1. Hyperbolic reference would require computer translation to a system useful to human operator.
2. Narrow-band FM transmitters may not provide sufficient accuracy.

(iii) Electronic Signpost

Small inexpensive transmitters are located in a grid fashion throughout the area of interest. They radiate a short range signal giving their location code. Vehicles receive this code and store the last one received. This is relayed on interrogation to the central station.

Advantages

Advantages are:

1. Low cost mobile unit.
2. Freedom from effects of multipath propagation.
3. Direct readout of any desired reference system co-ordinates.
4. Degree of resolution can be controlled closely.

Problem Areas

Possible problem areas are:

1. Acceptable system cost depends on developing a very low cost sign-post transmitter.
2. Accuracy limited by transmitter spacing, hence cost goes up as square of accuracy required.

Note: The basic electronic sign-post idea can be augmented in several ways by crude local direct measurements of derivative measurements. The latter is described in the following section.

(iv) Derivative (Compass-Speedometer) System

In this approach, each vehicle would keep track of its location and would transmit this information to the central upon interrogation. The vehicle would keep track of position by integrating velocity from the speedometer and heading from a special compass. This system could be combined with an electronic sign-post system

so that a very crude integration process would suffice and the system would automatically remove errors.

Advantages

1. Freedom from effects of multipath propagation.
2. Assuming the usual FM radio is used for interrogation, no new radio equipment is required.

Problem Areas

Possible problem areas are:

1. Unknown accuracy of compass in a vehicle over long term.
2. Unknown cost for various accuracy requirements.

(v) Use of Existing Radio Signals

The radio environment is filled with various types of signals. It is possible that measurements of existing signals could provide location information without additional transmitters. For example, the horizontal oscillator component of a TV broadcast signal would be a near ideal reference signal with extremely good coverage in most cities. Broadcast band AM and FM stations are other possibilities. By correlating signals received at a mobile and at fixed reference receivers, distance would be determined. The present FM radio would be used to relay the measurements.

Advantages

Advantages are:

1. No new transmitters.
2. Excellent coverage essentially "free".

Problem Areas

Possible problem areas are:

1. A computer is required at the control station to perform the required correlations.
2. Selection of signals would be specialized to such locality.
3. Problems in obtaining 24-hour operation.

The cost of an electronic sign-post type of vehicle location system is proportional to the area to be covered. Although it ought to be a practical technique for a large number of vehicles in a high-density concentration, for example a large-city police department or transit system, in its present form, its cost would be unacceptable for a widespread system containing a relatively sparse vehicle density. A sign-post system for the Chicago Transit Authority is now being installed.

Paper or laboratory versions of the other types of systems have been devised and some of them may prove viable particularly where large areas must be covered.

It is certain that the need for this facility will generate the required pressures on technology so that vehicle location systems will be in general use by 1977.

2.5 RECORD-FORM COMMUNICATIONS

There are many operating environments where it is desirable to have a lasting record of the message being transmitted. Examples of these requirements are the transmission of license numbers to police vehicles, the transmission of clearance orders to work crews in utility maintenance and construction and the transmission of instructions to any mobile operator who may be away from his vehicle from time to time. In the other direction, status and alarm information may be transmitted to the control centre to actuate a printer.

In Section 1.5 a mobile page printer is described. This device will meet all mobile record form communications requirements, including adaptation to facsimile. Where only short messages are required, strip printers at lower cost may be acceptable.

At the control centre a standard teleprinter is the most common device used for keyboard and printer.

Record-form communications have a further advantage as the digital transmission provides a measure of security beyond voice transmission.

The need for record-form communications is well established and demands on new technology during the next few years will be aimed at expanding hardware availability and reducing costs.

2.6 MOBILE VISUAL SYSTEMS

These may take the form of broadcasting to mobile units or relaying of picture information to a control centre.

Special law enforcement broadcasts of an"all-cars" nature could be received on a television screen in each car. For example, during a bank robbery, a picture of the scene televised from the bank's own cameras would be relayed to the central broadcasting studio and transmitted from there to all cars. Thus every car in the vicinity would get an idea of what was happening in the area and perhaps even what the wanted persons look like. A transmission of this type may have to be scrambled or coded to prevent unauthorized reception.

Another law-enforcement application would be to view a riot scene via television carried by a helicopter. Again, a relay of the picture to the central studio and a video rebroadcast to the cars will give an immediate exact picture of events as they are occuring.

A means of narrowing the field of view of an airborne camera would enable an individual person or vehicle to be tracked, rather than viewing an entire area. An untrained viewer or a person unfamiliar with large, over-all aerial views may find it difficult to recognize anything in an aerial picture, but a man in a police car ought to be able to orient himself by turning on his car's blinker light to see where he is located in the scene.

Television may also be a useful adjunct to a helicopter control centre during forest fires or civil disturbances. A camera in the control centre, trained on a status map with markers to show locations of vehicles, persons, activities, thoroughfare blockages, firebreaks, etc., would enable valuable information to be transmitted to supervisors, policemen, or firemen at the scene of action.

Another possibility would be to process the video information received from an airborne TV camera for direct display of certain features on a control centre status map, and then televise an image of the map to screens at whatever locations are desired. Furthermore, by remote control, the map-viewing camera could be moved to view particular sections of the map, or close up, to get as much detail as desired.

For map viewing, slow-scan TV may be quite practical, since changes are not likely to occur faster than the system can handle them. As another application of this system, the patrolman can view "show-ups" being conducted at the police headquarters. Similarly, daily bulletins of the police or other organizations can be viewed remotely to avoid the accumulation of excess hard copy in the vehicle.

Television equipment to provide any of the information broadcast services suggested in this section is readily available commercially. To implement a public services television system would merely require a policy decision to proceed, a source of adequate funds, and authorization by the DOC.

2.7 SAFETY ON THE HIGHWAYS AND WATERWAYS

Various public safety agencies, primarily fire departments and the police departments have expressed an interest in systems to enable a citizen in distress to call for assistance. The assistance required may take a considerable variety of forms. For medical aid, a doctor, or ambulance, or oxygen equipment may be needed. A mechanic or tow truck to assist with a disabled vehicle is a frequent requirement. A rescue squad may need to be summoned in the event of a cave-in, explosion, train or airplane wreck, etc. Also, but not least, the fire department or police department may need to be called.

The wire networks of the telephone companies provide the usual communications medium for calling for help in populated areas. Some localities employ emergency call boxes mounted on posts at street intersections and connected by aerial wire but more often by buried cable to a police or fire switchboard. A number of communication schemes have been proposed to assist the motorist whose vehicle becomes disabled

along a limited-access highway, employing either radio or wireline calling equipment. Several of these systems are presently being evaluated experimentally.

It would be desirable to provide a means whereby a person in an isolated location may send a call for help in an emergency. A rescue radio could be mounted on poles in some areas, but would have to be well anchored or protected to prevent loss by theft. Since it would probably be impossible to prevent unlawful transmissions, the installation of pole mounted units may have to be limited to only the more remote regions.

Portable Radios for Emergency Aid

One possibility would be a special portable radio that would be carried by campers or others who go into out-of-the-way areas. Such a unit could be purchased at a relatively low price and might be considered to be a part of necessary camping equipment. It may eventually become a required safety item, similar to the life preservers required on water.

The usage of a radio of this kind might be expanded later to a unit that each vehicle would carry on ordinary trips on the highway. However, there is a problem of channel capacity since the number of units in use would be very large.

To control false alarms or malicious transmissions, the owner of each rescue radio could be registered or licensed similar to the registration of owners of automobiles or guns. Additionally, each radio could be provided with individual coding circuits to enable the source of any transmission to be identified by its transmitted code.

The basic pole mounted radios and portable radios mentioned here are already commercially available. Special coding or signalling circuits are technically,entirely feasible. Since the portable radios are low-powered and consequently have rather short ranges, the emergency call system may require strategically-placed satellite receivers to extend the effective range. Satellite receiver systems, with automatic selection or voting, also are currently readily available. Non-equipment oriented actions required to implement a system for calling for emergency aid includes setting policy, selecting a particular technique, and obtaining allocation of suitable radio frequencies from the Department of Communications. More details on pole mounted systems are presented in the next section on detection of off-the-pavement vehicles.

Detection of Off-the-Pavement (Disabled) Vehicles

In the field of highway engineering, the desirability of removing a disabled vehicle from the shoulder of a highway or of putting it back into service as quickly as possible is well recognized. The principal reason for this attitude is that the disabled vehicle constitutes a potential obstruction having a dangerously high probability of being involved in a collision before it is removed or serviced. Other reasons are the loss of time to that vehicle's driver and passengers, and the slowing (to look) of the traffic passing by, with the consequent probability of a bunching or stoppage of the traffic.

A number of approaches to detect and/or locate disabled vehicles along limited-access highways have been proposed by various interested persons. The interim solutions all require action by the motorist. They are:

Radio call boxes, located just a few minutes of walking time apart along the highway provide motorists with instant voice communications with a police dispatcher. The highway emergency radio system should be dependable under the most severe conditions. Each radio call box is powered by a rechargeable battery that provides all-weather operation, even after several dozen emergency conversations. When a motorist uses the call box, the signal transmitted to the base station identifies the activated call box eliminating the need for direction to the emergency scene. If a handset has been removed accidentally or by a vandal, the dispatcher knows about it and can send a nearby police officer to investigate. If a handset is not replaced properly after use, the call box automatically stops transmitting after a short interval to minimize battery drain.

A telephone system, either conventional or sound-powered, installed along the highway, provides a communication link between the motorist and a central location. The motorist can describe the exact nature of the difficulty to the central operator.

Another system employs solar batteries and digital encoders, but does not provide communications. The call-boxes are located at half-mile intervals. The motorist walks to the nearest box, presses a button and signals his location and the nature of his difficulty to a central station.

Several years ago a system was designed primarily for remotely controlling road signals, but which can incorporate telephone circuits to aid the stranded motorist. As a protection feature, the central location receives a signal if a telephone is disconnected, which might deter vandalism to some extent.

An approach that enables the motorist to call for help without leaving his car has the advantage of safety, since the probability of a motorist being injured while walking along the edge of a highway to a call-box is high. Furthermore, if an emergency aid vehicle happens to be nearby when it receives the dispatch, it may reach the disabled vehicle many minutes before the motorist on foot returns. A low-powered transmitter in the vehicle, perhaps built as a part of the entertainment radio, sends the distress signal to a wayside receiver, which relays the message by radio or buried cable to the central location. Some of the problems connected with this system are described later.

Another possibility is the application of a resistance-measuring technique used by power companies to locate short-circuits in power lines. A system of this type would require: burying a cable along both sides of the highway; placing switches that can short-circuit the cable at half-mile intervals along the cable; and placing the resistance-measuring bridge circuit and an alarm at a central station. When a motorist closes the nearest shorting switch, the alarm in the central station

announces that a motorist is stranded and the resistance measuring apparatus, which may include a digital voltmeter as an output device, gives a numerical indication of the mileage to the motorist's location. An indicator lamp mounted near the shorting switch comes on when the signal is sent by the motorist and is reset from the central station when help is dispatched. This serves to acknowledge the call, thus assuring the motorist that aid is coming. If more detailed communication is desired, simple codes could be devised to transmit additional information to a central monitor.

Ultimately, systems will be developed that will require no action by the motorist and that will signal the central station automatically when a vehicle is driven off the pavement. Taken alone, such systems will probably be too expensive or inefficient to warrant their adoption. The feasibility improves markedly when such systems are included as part of the "ultimate electronic highway". In that case any detector, whether magnetic, electronic, infra-red, mechanical, television, or other, may serve as the basis for the location system.

The electronic highway will require a communication network for guidance, to maintain the vehicle in its lane, and for maintaining safe speeds and distances between vehicles. The detection and location of disabled vehicles would then be more feasible economically if the communication network can be shared.

Automatic detection of a vehicle leaving the pavement must incorporate a time delay to avoid false alarms caused by vehicles that leave the highway temporarily and return.

The ultimate electronic highway is likely to evolve over a long period of time. The total cost of such a system will be very high on account of the thousands of miles of expressways and millions of vehicles that will have to be equipped. It would be inefficient use of an expensive facility to implement it on a piece-meal basis of only a few miles of road and a few hundred vehicles at a time. Thus the system will probably not come into being until the need becomes great enough to balance the cost of an economically large fraction of the total system. Because it appears that the realization of an overall system will occur in the uncertain distant future, only the systems requiring driver action are compared below.

The two-way highway emergency system appears to be the most attractive interim system from the standpoint of reliability and cost. There are no expensive telephone or ac power lines to install or maintain. Additional call boxes can be installed at any time without costly and time consuming wiring or digging. Being a radio system, it can also be used to co-ordinate emergency services or expanded to include such features as sign activation and traffic data gathering.

The major drawback of the telephone network linking roadside stations to a central aid station is its vulnerability to vandalism. Telephone companies have experienced relatively high losses on exposed public telephone facilities. High initial cost is the main drawback of the solar battery type of system. The problems connected with a distress

transmitter mounted in the vehicle are several, including high overall cost, related to the huge number of vehicles to be equipped, high likelihood of inadvertent or malicious false alarms, and high initial cost of wayside receivers.

The resistance-measuring technique compares favourable against the other non-radio systems. It is not recommended as a final solution, but its initial cost appears to be reasonable for an interim system. It does not require expensive components, such as telephones or radios, but the buried cable has a high installation cost per mile. It would not invite vandalism and its maintenance requirements would be minimal. Eventually, it could remain in use in the ultimate electronic highway to conduct power to the electronic circuits that would be required in the final system.

At least one example of each of the communication systems described above for detecting or locating a disabled vehicle has been installed somewhere in the United States on a pilot basis. Such experimental operation will provide the means of evaluating the various systems under actual field conditions and real situations. The results of these evaluations should begin to appear soon in the technical reports of the various Federal and State Highway Agencies that are involved.

All of the interim systems described in the foregoing are available now.

2.8 SECURITY AND PRIVACY

For many years the military services have been interested in making their transmissions of information secure, that is, to prevent a possible enemy from intercepting messages and exploiting the information contained in them. Whenever a new transmission technique was developed, the military people demanded some means of scrambling or enciphering the transmitted information. Those demands became satisfied eventually and devices are now available for every application. Protection can be provided for information in every known form, whether speech, tones, pulses, telegraph, teletype, television, facsimile, or other; for any wire, cable, or electromagnetic transmission medium; and for application to a fixed plant, mobile vehicle, aircraft, or naval vessel. A complete line of devices has been devised, varying widely in the degree of security that is provided. It covers the range from simple speech privacy equipments to complex data processing apparatus that protects (on a statistical basis) individual messages for periods measured in years. The cost of the equipment varies with the degree of security provided, but the cost does not rise as fast as the security.

As the volume and complexity of police work have grown, the police agencies have begun to feel an increasing need for a low-priced speech privacy or speech security device. One reason for this need is that the professional criminals are acquiring radios tuned to the police dispatch channel so that they can listen to the messages and avoid arrest. Another reason is the growing number of "police buffs" in some cities. These citizens use low-cost short-wave radios or adapters for their

broadcast band portables to "scoop" the news and be first at the scene of action. However, the police prefer to investigate trouble and act without thrill seekers on the scene.

The expressed need for speech privacy in police work has resulted in the commercial development of several models of scrambler. The prices of these units range from about $250.00 to $2,000.00 apiece. Two units, of course, are required for a usable communications link, one to scramble the information at the transmit end and the other to restore the information at the receive end. Generally, each unit has the capability of both scrambling and unscrambling, but not simultaneously, as in full-duplex operation, because common circuits are shared by both functions.

The simplest scrambling technique employed by present units intended for police radio use is the inversion of the frequencies in the speech band. The low frequencies are translated to the upper part of the band and the high frequencies to the low end. This approach provides protection only against the casual or "nuisance" listener, since several drawbacks render it relatively ineffective against a determined listener. With practice, some persons develop the ability to understand inverted speech, especially if they can tape record a scrambled conversation and listen to it repeatedly. Another drawback is that an ordinary receiver, slightly detuned, will reinvert the speech to understandable form. A third point is that very few "codes", obtainable by shifting the reference frequency about which the spectrum is translated, are possible and that some manufacturers make no choice of codes available at all.

A more sophisticated approach splits the speech band into two or more segments, generally five, and provides means of selectively shifting and/or inverting each segment to or within another part of the band. This approach provides for the selection of a moderate number of code combinations and is the scheme that has been in use to provide privacy and eliminate understandable cross-talk in undersea telephone cables for several decades. Here again some practiced listeners can learn to understand the scrambled speech. Furthermore, a determined electronics technician could readily build an unscrambler and quickly determine the particular combination of segment inversion and/or shifting that has been selected. Protection against a practiced listener requires the division of the speech band into ten or more sub-band segments. This requires more filters, which are expensive components, than the five-band approach, since one set of filters is needed per sub-band, and the quality and cost per filter must go up as the number of sub-bands is increased.

A still more sophisticated approach, and a much more expensive one, employs data processing circuits to automatically change the scrambling combination of the multiple sub-band system, at a rate of a few times per second (in the range of 1 to 20 per second). A means must be provided to switch the code combinations in synchronism at both ends of the communication link. Then, to prevent unauthorized detection, the pattern of switching of code combinations must also be protected. This additional protection can be provided, also at considerable cost, but the methods are too complex to discuss here.

The ultimate degree of security is obtained by digitizing the speech signals, then encoding the digits with a data processor. The digitizing processes generally used are PCM (pulse code modulation) or Δ-M (delta modulation). Other processes are possible but are more difficult to encode. The disadvantage of digital, or pulse systems is that much greater audio bandwidths are required for transmission of the signals than are avalilable in the channels presently allocated to the land-mobile radio services. DOC action would be required to obtain wideband channel allocations. The present nominal 3 kHz speech bandwidth requires a minimum pulse transmission rate of 18 to 25 kilobits per second for reasonably good voice intelligibility. An audio band of about 12 to 19 kHz and an FM RF bandwidth of 50 to 75 kHz respectively, is required for reliable transmission of these pulse rates. Until the high cost speech-bandwidth reduction systems can be lowered to a reasonable level, we recommend the use of wideband systems for those applications requiring a high degree of speech transmission security.

The safeguarding of the speech security equipment and of the information regarding its use has several ramifications that require some clarification. If we assume that a professional criminal will equip himself or his vehicle with a radio capable of receiving police calls, we must also assume that he will attempt to decipher the scrambled messages when he discovers that the police are using privacy or security equipment. A simple solution for the criminal is to steal a police privacy device, and to learn the code or codes that are in use if the device is a multicoded type.

Now, several of the privacy equipment manufacturers state that their equipment can be employed in fleet operations. With the base station and every car or selected cars in the fleet equipped with a privacy device, all cars can receive private messages at the same time. We do not recommend such a practice. If the criminal has a captured privacy device and knows which code is in use, he will also hear all messages and be able to adapt his operations accordingly to avoid arrest. Furthermore, it may be difficult for the dispatcher or the fleet members to determine quickly that a privacy device had been stolen, or that someone is listening to their conversations.

A better practice is to operate in the privacy or security mode between paired equipments only — never more than two persons per communication link, and, further, to change codes frequently according to a pre-arranged plan. Thus a separate pair of equipments and a different code are required for each communications link. However, with this arrangement, even though the criminal acquires one of the privacy devices, he destroys only one of the communications links leaving the remainder intact and undeciphered. Moreover, the probability of finding the correct code to decipher the messages will be very small if a sufficiently large number of possible codes is available.

Besides providing security against criminal listeners, the use of different codes for each pair of users keeps various operational teams within a police department from listening to each other's conversations. This may be desirable in the case of investigative or undercover squads

operating at the same time, but a disadvantage if groups of several men need to work on a single problem. In the latter case, no practical solution is known, and a decision must be made on whether to provide a secure channel to all men in the group or limit it to user pairs only, i.e., dispatcher to car, or car to car.

As stated earlier, the simpler speech privacy devices are already available at moderate prices. More advanced devices, for either speech or other types of information content, can become available within a reasonably short while after the prospective users resolve the operational problems and define the methods of use.

2.9 MOBILE AND PORTABLE ALARM AND SIGNALLING

An example of an explosive, unforecast use for a land-mobile communication system that has developed recently is an alarm and status reporting system to be used to protect schools and other public buildings against vandalism.

Strategically-located detectors which sense alarms or changes of status activate a radio transmitter which, in turn, sends a coded signal to a receiver at one or more centrally-located monitoring stations. The receiver actuates a visual, audible or recording printer alarm. Multifunction encoders at the remote site enable a variety of conditions to be monitored. For example, one sensor may monitor building entry, the others may monitor fire or smoke alarms or even whether the heating system is operating.

This type of alarm system has the advantage that it does not depend upon telephone circuits or power lines which can be destroyed prior to the criminal action. It is also highly portable, flexible.

This alarm reporting system is applicable to a wide variety of needs, such as monitoring conditions in an oil field or along a microwave system independent of the microwave circuits themselves.

Just as the alarms can be transmitted by radio, so can control signals to actuate devices remotely. For example, valves can be closed in the oil field and standby generators can be started up on the microwave system. An unattended sea-going barge can be controlled from its tugboat; slave locomotives can be controlled by wayside control or by master locomotive. Radio control of cranes is an established technology.

There is an increasing demand for radio-alarm signalling and control equipment. While large blocks of spectrum are unlikely to be required, there must be consideration given to the need for channels in this type of service.

2.10 EMERGENCY MEDICAL MONITORING

In Electronics News, page 44, September 9, 1968, a new technique in medical electronics and communications was publicized. An ambulance

service in Los Angeles had tested a modification of NASA's electrode body function monitor. The system transmits the heartbeats of a cardiac patient over the ambulance radio to the ambulance service dispatch office where the information is relayed by a special telephone line to an EKG recorder at the hospital. Thus a doctor can examine the electrocardiogram and make preparations for the reception and care of the patient while the patient is en route to the hospital via ambulance.

Electrical signals from the patient's heart are picked up by "dry-spray" electrodes attached to the chest. The heartbeat signal is modified by an amplifier-FM modulator. The FM tone is played through a small speaker into the microphone of the ambulance's two-way radio. An FM/FM transmitter wave results.

With the present system, voice and heartbeat information cannot be carried simultaneously. The availability of multichannel FM radios should make it possible eventually to send information on other physiological functions, such as blood pressure, pulse wave velocity, respiratory volume, skin temperature, and many others. Some of these could be sent simultaneously over a single radio frequency by using data multiplex techniques.

The systems described here are feasible now, will save lives and be in widespread use in five years. A secure channel will be required ultimately for this service.

2.11 HIGHWAY ROUTE AND GUIDANCE SYSTEM

Automatic automobile driving has received considerable attention in the technical literature. With the prospect for improving highway safety and affecting the well being of so many people, this is understandably so. The problem is extremely complex, however, and even our advanced technology at this time yields only a partial solution.

Essentially three problems must be solved. The first, lateral control or steering is relatively easy as a radiating cable in the roadway with appropriate sensors in the vehicle would seem to be within present day technology. Longitudinal control (speed, acceleration, braking) is more difficult and various means have been proposed, some depending upon relations with a lead vehicle. A system using laser frequencies has been proposed to control the distance between the vehicle ahead automatically. The third problem is combining the two systems and providing the necessary self-test and backup sub-systems.

The automatic automobile driving system is unlikely to use spectrum which is competitive to land-mobile users. However, the advent of these systems, probably in the late 80's will almost certainly generate additional communications requirements for the vehicle since relieved of his driving responsibilities, the driver may well involve himself in other tasks requiring communications.

2.12 AIR AND WATER POLLUTION MONITORING AND POLICING

In air pollution control, mobile radio communications has offered the only practical means of contacting pollution inspectors and getting them to the scene of a violation within a matter of minutes. This is critical because if the inspector arrives after the violation has ceased, there is no evidence and the violator cannot be prosecuted.

Oil pollution of the Great Lakes by shipping has recently come under surveillance by the Government and in this case an aircraft, equipped with mobile radio on the marine channels, can contact the ships captain and coast guard stations relative to violation. Aerial inspection, in fact, is the most effective way of combatting air pollution, both from the standpoint of observing the violations and photographing it. It also enables the inspector to reach the scene quickly while the evidence is fresh.

With increasing befouling of our environment, we need the most effective means of control. Frequencies for this service must have priorities equivalent to those for public safety.

Automatic monitoring of the environment can also be effected using radio channels. Sensors at strategic locations will detect pollution levels and automatically report values when interrogated by a central station or when values exceed a certain preset maximum. Such a system is similar to those presently in use to monitor meteorological functions.

3. FUTURE TECHNOLOGY AS AN AID TO SPECTRUM CONSERVATION

Introduction

Because of the continued development of new ideas for the use of mobile radio and technological advances which makes these uses possible, the pressure on available spectrum is sure to expand. In the past few years, there has been a rapid increase in the development of such new uses because of the increasing needs for communications to meet the problems of law enforcement, bus and subway transportation safety, air pollution and other governmental operations, as well as to meet the needs of the steady growth of our economy.

As a result of these needs, vast sums have been spent on research into improved communications methods and technology. Some of the initial results of this research, including the mobile teleprinter, the vehicle location systems and medical monitoring, will soon be in everyday use.

These systems will require additional spectrum, mainly because they will require more air time but also because the improved efficiency of operations will result in a rapid and substantial expansion of the need for additional spectrum for these uses.

There is no doubt that the present spectrum can be managed and utilized in a more efficient manner and some suggestions in this regard are discussed in this section. There is certainty, however, that burgeoning uses and expanding technology will, in a few short years, result in full utilization,and consideration must be given now to this eventuality so that orderly planning and development can proceed.

This section discusses specific techniques which are in service or have been proposed, in the three highly inter-related areas of:

Bandwidth

Modulation Methods

System Methods

and which have the particular objective of passing traffic in the most efficient and effective manner between base and mobile stations, mobile and base stations, mobile and mobile stations. Generally the traffic will be in the form of voice message two-way conversations, however it must be recognized that one-way paging messages, consisting of signalling only, or in conjunction with voice, data messages for teleprinter, identification, location, etc., will form an increasing portion of the total. Considerations will, however, be substantially the same as for a single voice circuit except for possible variations in the rate of transmission.

The traditional method of transmission in the radio spectrum for the majority of traffic has been by direct access to individually assigned channels, although the same channel may be shared by others, desirably geographically separated but frequently within the same area. Typical exceptions to this approach have been point-to-point multiplexed microwave, UHF/VHF circuits, multiplexed FM Broadcast circuits, mobile telephone service and community repeaters, all of which intentionally share some common facility in the same area.

The mobile radio system is examined in relation to its environment, bandwidth and various modulation methods — Wideband FM (WBFM), Narrow Band FM (NBFM), Sliver Band FM (SBFM), Amplitude Modulation (AM), Single Sideband Reduced Carrier (SSB), Double Sideband Reduced Carrier (DSRC), Pulse Code Modulation (PCM), Pulse Amplitude Modulation (PAM), individual, trunking and multiplexed system methods.

3.1 CHANNEL SPLITTING

The EIA has clearly shown in its comments to FCC Inquiry[15] that impulse noise alone has already been responsible for the decreased area coverage resulting from channels being split from 60 to 30 and 40 to 20 kHz, and shown that, with equipment at the present state-of-the-art, a minimum channel spacing of 20 to 25 kHz is accompanied by a noticeable amount of performance degradation. Further, while 15 kHz channel assignments would initially put a few more users on the air, such a plan would disrupt many existing systems and reduce area coverage to the point where the number of base stations required to cover the same area,

for the same class of service, would increase at a rate greater than the number of assignable channels would increase.

Apart from impulse noise, interference is caused whenever a transmitted frequency spectrum intercepts the receiver selectivity curve as a result of —

(a) Interception by transmitted carrier,

(b) Interception by modulated sidebands,

(c) Interception by transmitter noise.

At frequencies very close to the transmitter carrier, the noise level will be about 45 dB below carrier level and attenuate to about 80 dB at frequencies 15 kHz removed from the carrier. Modern technology is unable to further attenuate close-in transmitter noise spectrum.

A knowledge of the mechanisms and the ranges at which interference is produced, shows that with frequency separations of less than 25 kHz, problems rapidly increase and even frequency errors of 2 × .0005% (Transmitter plus Receiver) cause drastic changes in the ranges at which interference will occur. The conclusion must be that about 25 kHz spacing is minimum when the only considerations are the effects of transmitter radiations intercepting receiver selectivity.

The channel spacings 20 kHz and 30 kHz therefore represent compromises to the 25 kHz spacing, however, with the state-of-the-art producing less absolute frequency error in the 30 to 50 MHz band, 20 kHz might be regarded as a reasonable compromise in this case.

As stated at the beginning, impulse noise is the most serious interference consideration and Figure D1 shows that its effects are highly related to frequency error (stability). Comparison between a wideband WBFM and to narrow band NBFM system shows that a 10 PPM error must be reduced to 4 PPM for the same degree of degradation, hence any proposal to further reduce channel separation to say, 15 kHz or less, would demand further improvements in stability, feasibility for which is limited by state-of-the-art, the economics of highly stable oscillators, poor weak signal performance of AFC systems, field maintenance equipment and techniques.

3.2 MODULATION TECHNIQUES

A favoured method of reducing bandwidth in point-to-point circuits where impulse noise is seldom encountered, is the use of Single Sideband Amplitude Modulation, (SSB). Figure D2 shows a simple SINAD comparison of SSB with WBFM, NBFM and DSBAM. More importantly, Figure D3 shows articulation comparisons for SSB, SBFM and NBFM both in the presence and absence of ignition noise.

While the conclusions may be drawn that in the absence of impulse or any other interference, AM produces greater SINAD than FM, at very low signal strength, the quality of service is so low that there is no

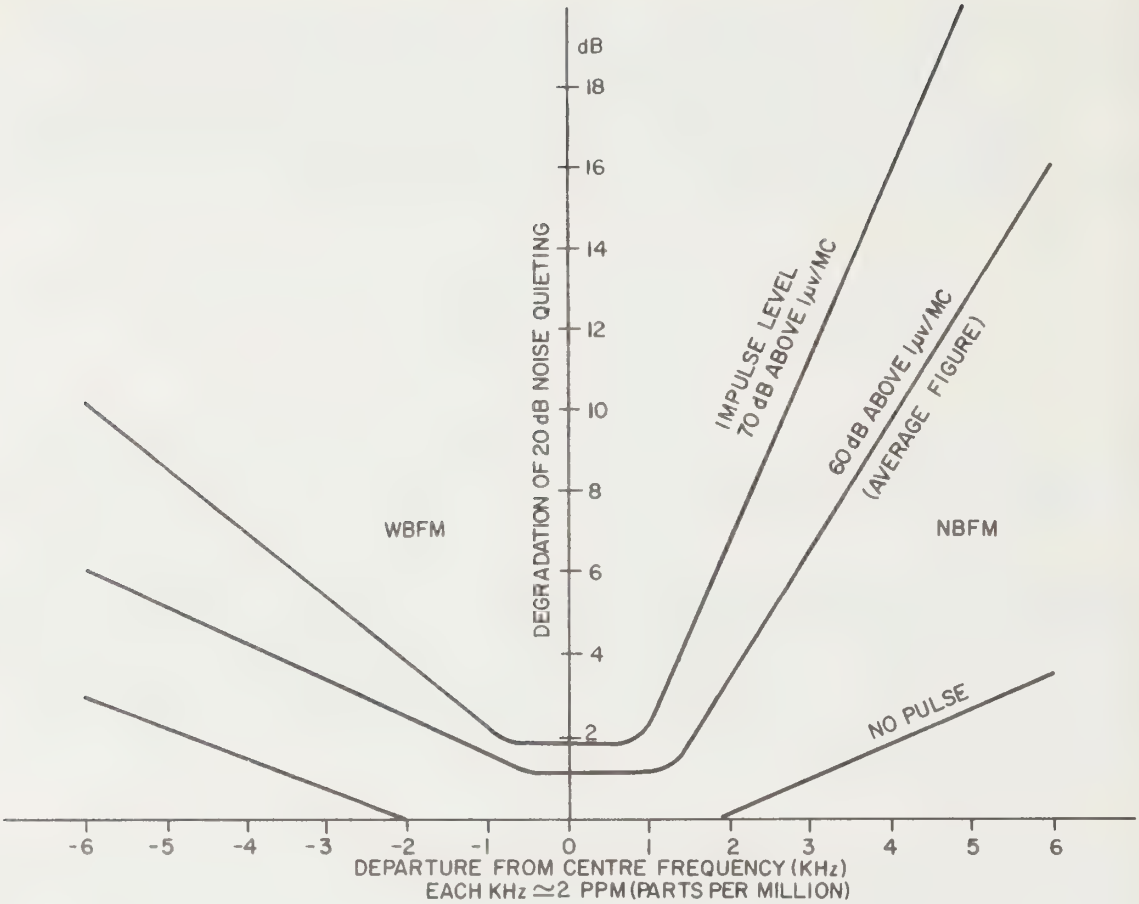

Fig. D1. Degradation of 20 dB noise quieting vs departure from centre frequency as a function of impulse noise 450 Mc receiver.

real net advantage and that the FM improvement over AM systems reduces rapidly as the frequency modulation index decreases, we may, therefore, rank them in sequence of superiority under normally expected signal levels as follows:

1. WBFM
2. NBFM
3. SBFM (6 kHz bandwidth)
4. SSB AM
5. DSB AM (6 kHz bandwidth).

The impulse noise conditions show the even more dramatic separations in the ranking between

1. NBFM
2. SBFM
3. SSB AM

with the inference from the SINAD tests that WBFM is most superior and AM least effective.

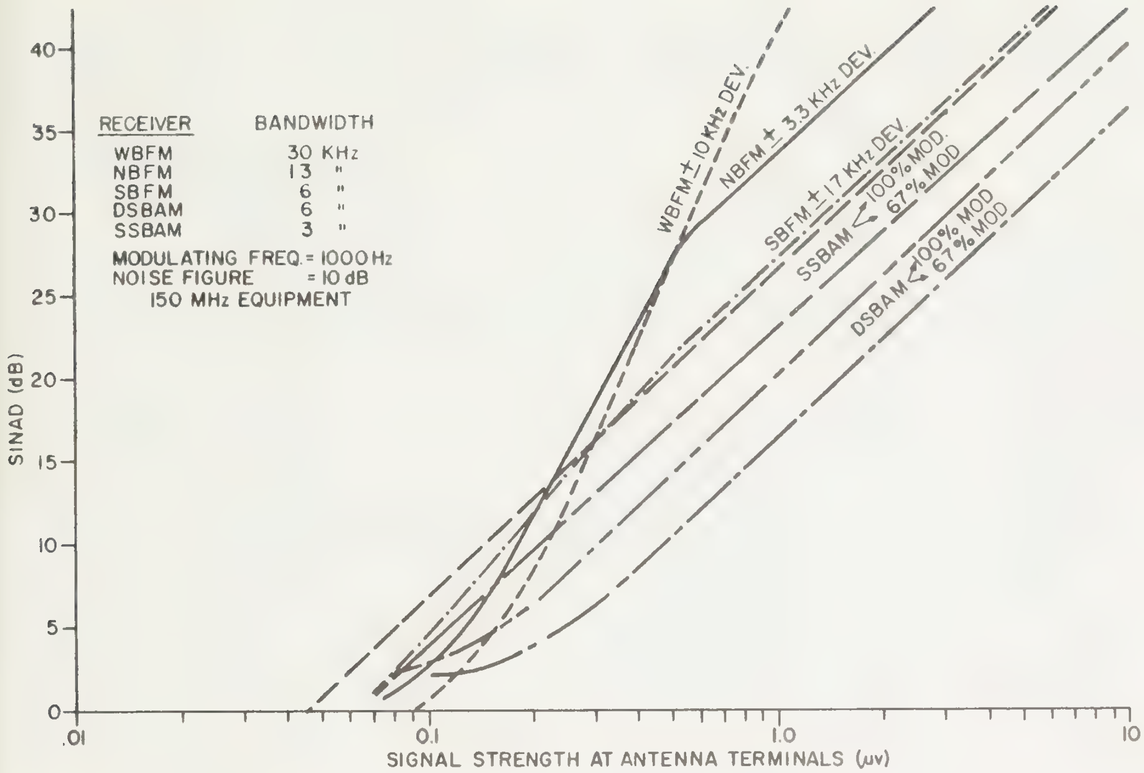

Fig. D2. SINAD vs signal strength.

Double sideband suppressed or reduced carrier will perform better than SSB but inferior to SBFM. Single sideband FM SSBFM is mentioned for completeness only,since while it is single sided, its spectrum is approximately 4/3 that of FM, its asymmetry results in a 10 dB increased degradation in the presence of impulse noise and could not be expected to provide any more channels than SBFM.

Similarly, any simple application of pulse techniques appears out. There is far too little frequency space for PCM, while PAM requires a good degree of separation between successive pulses of cross-talk is to be avoided. In a city, successive pulses will be highly overlapped because of multiple path propagation[16].

To sum up, no matter what the mechanism for producing narrower bandwidth, the result is to produce greater degradation in the presence of impulse noise. The inherently greater susceptibility of AM to this prevalent kind of noise outweighs, by itself, all other arguments against AM for land mobile service.

3.3 TRUNKING

Trunking has been widely used in the telephone industry and in this application has provided rather dramatic improvements in the number of users that can be accommodated per channel. Because of this, some

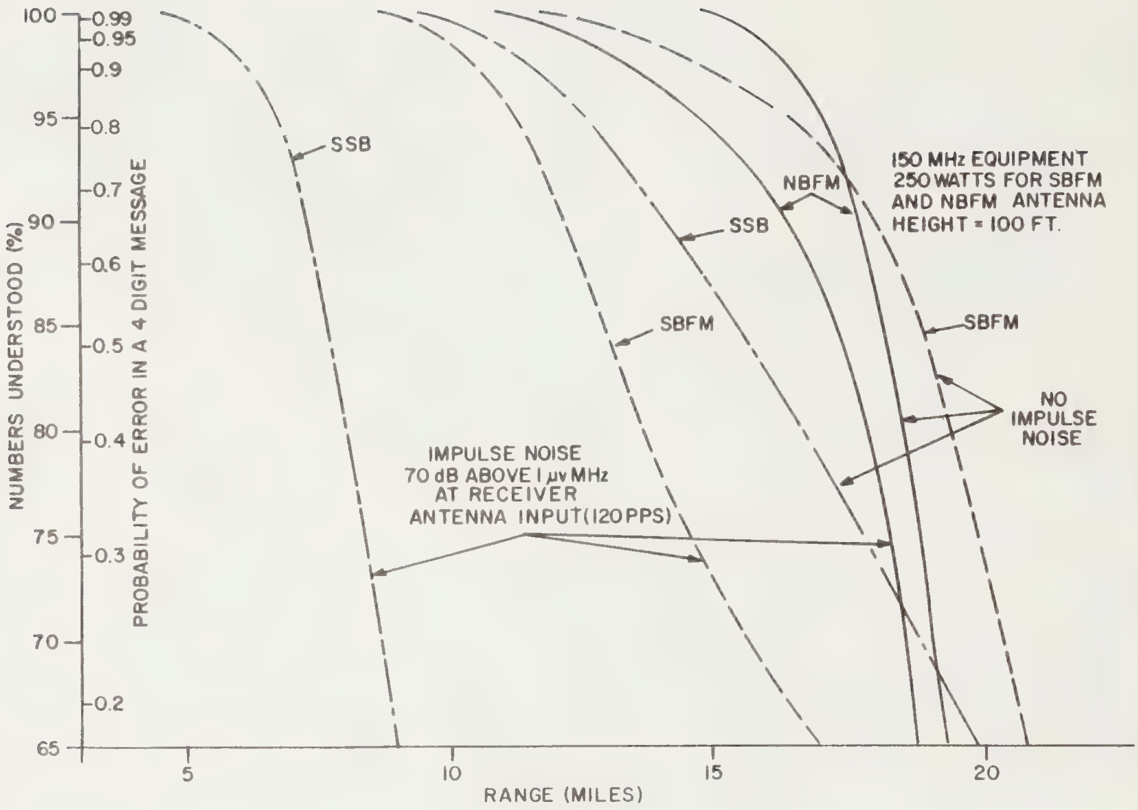

Fig. D3. Coverage range of base station vs percent of numbers understood at an average location on the perimeter of the coverage area for equal power to the base station.

observers have suggested that trunking offers a solution to a broad range of frequency congestion problems in the land-mobile radio services.

Dr. Jona Cohn, with William Braun and Eugene Bruckert have made a comprehensive review of mobile trunking proposals[17] and the associated cell concept[18] and drawn attention to the key points.

3.3.1 Variety of Mobile Radio System Needs

While the mobile radio service is characterized as voice communications, it is well to recognize the large variety of specific requirements which are served. The needs for system coverage vary from in-plant communications to area wide networks. Some users operate primarily in the dispatch mode, while others have heavy usage of mobile-to-mobile communications. Still others need communication to the man and are therefore limited to portable equipment. Some use short-range communication at field sites, and others use one-way voice and paging messages to their personnel. Also, new functions are beginning to appear such as vehicle location, computer inquiry, mobile teleprinters, status interrogation, and alarm reporting.

These differing requirements have led to different radio system configurations to meet these needs, including single-frequency simplex, two-frequency simplex, and repeater systems. Each of these configurations can represent an optimal solution for specific needs.

3.3.2 Radio Message Lengths

As described in the following examples, the more disciplined radio systems have message lengths which average between five and the twenty seconds in length. Message length refers here to the total time required to complete the series of one-way transmissions which make up the full two-way conversations.

In a study of police communications by the Illinois Institute of Technology[19], message lengths were measured and found to average as low as 6.14 seconds. A recent study by Motorola of the 150 MHz Business Service channels found an average message length of 14.5 seconds. Figure D4 shows the plot of the distribution of message lengths from which the 14.5 seconds average message length was determined. It will be of interest to the technical reader to note that a replot of the measured data into the form shown in Figure D5 shows the distribution to be close to a negative exponential function. In later discussions an exponential message length distribution has been assumed.

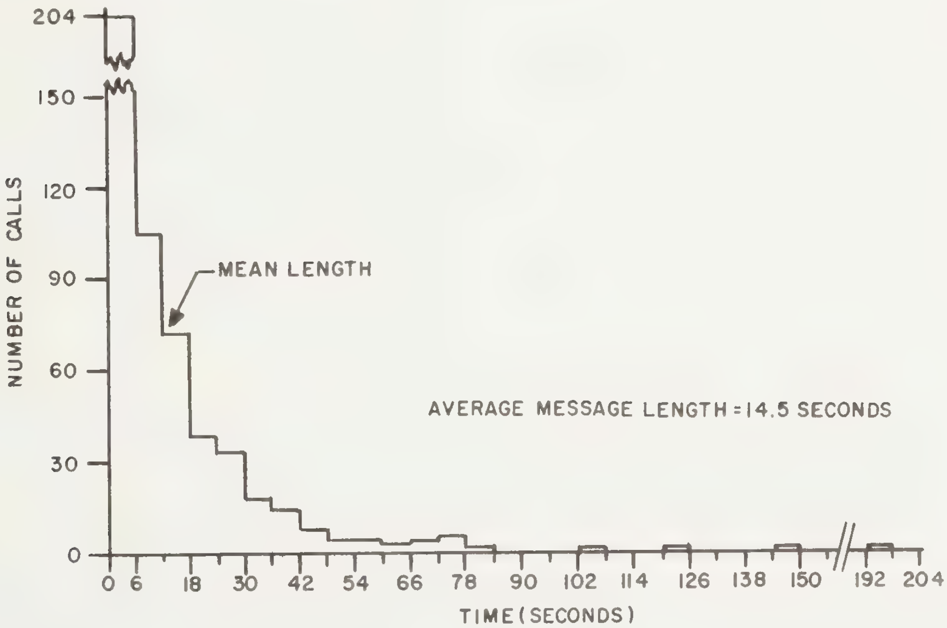

Fig. D4. Business radio message lengths.

To illustrate the difference between these short messages, such as police (6.14 seconds) and business (14.5 seconds) and telephone experience, note that these messages are completed in much less time than the 25 to 35 seconds typically required just for dialling and initiating a call in a telephone system.

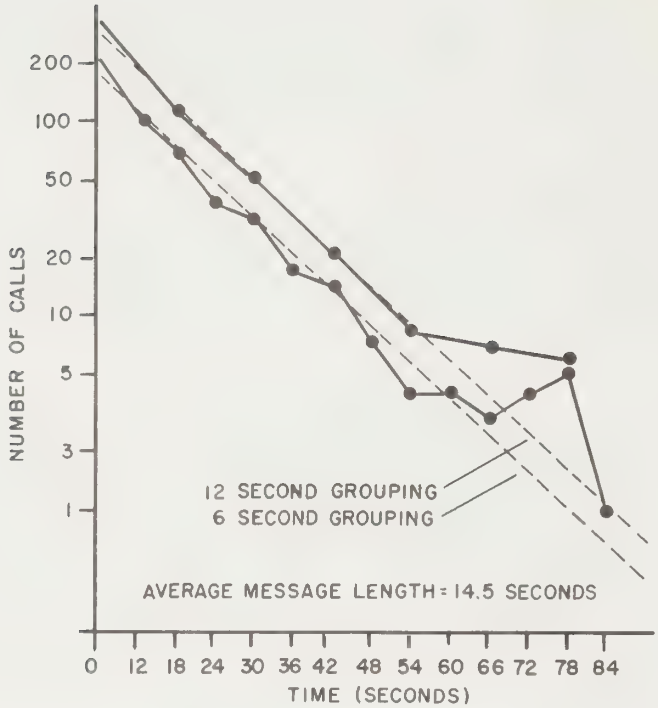

Fig. D5. Business radio message lengths.

For these short message lengths, single channel systems are practical at average loading levels of 50 and 60 percent, since each user knows that if the channel is busy he can monitor with the assurance that in a matter of some seconds he can proceed with his communications. This is then a fundamental difference between the public telephone and private radio system users. Because message lengths differ by more than ten to one, private radio users obtain much higher single channel loading without the use of trunking.

3.3.3 Telephone Trunking

Before examining in detail, the gains and losses due to trunking, it is important to understand the basic concept behind the previous experience with telephone trunking.

Consider two small groups of telephone users at two separate locations, whose telephone access from one group to the other is limited to a single channel. As telephone users we are aware of the fact that telephone conversations typically last from three to four minutes and are sometimes much longer. Consider the service to a user of our simple system if the single interconnecting channel were permitted to have an average load of 50%. Half the time a call would be attempted, the channel would be busy and very significant delays would occur. In fact, the delays would be so frequent and so long as to make the service unacceptable. In this single channel situation, it would be necessary to limit the average channel use to some low value to achieve an acceptably low access delay. Typically one would have to reduce the average use to less than 10% so that 90% of the time a wait would not be necessary.

If however, it is possible to combine larger groups of users at two locations, and apply trunking i.e., give each user access to a number of channels, it will be possible to use average loadings of 50% on these trunked channels. This is because the probability of all the channels being busy at the same time would then be acceptably low such that a 90% probability of no waiting is still achievable.

Note that 50% compared to 10% is a 5:1 increase in the loading capacity per channel. Stated another way, however, it is mandatory in telephone practice to resort to trunking in order to obtain reasonable loading and avoid the necessity of limiting the average loading to a small percent.

3.3.4 Theoretical Trunking

Let us now consider trunked channels on a more quantitative and analytical basis. The idealized theoretical queuing analyses results in the curves shown in Figure D6. The curves have been taken from

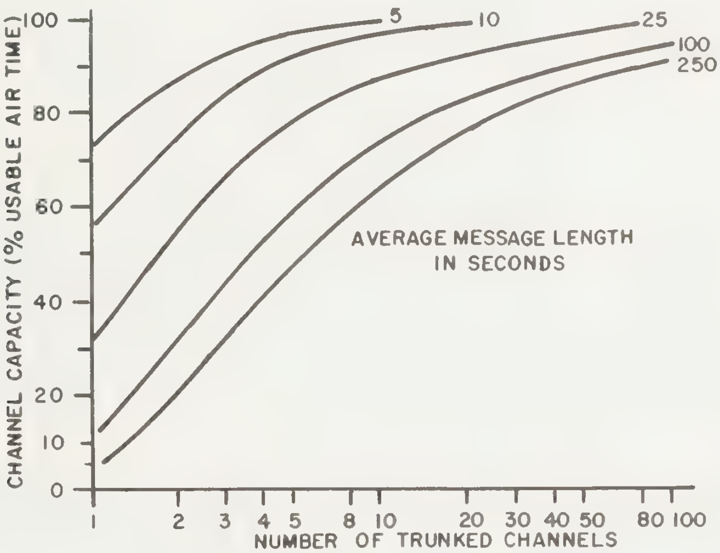

Fig. D6. Theoretical trunking efficiency.

published delay tables[20]. They assume random arrivals of calls for service (Poisson distribution and exponential holding time message lengths). Here we see plotted the percent of usable air time available as a function of the number of channels in the trunking system. A key parameter is the average length of message, and curves have been calculated assuming average values from five seconds to 250 seconds. A ten second average access time was chosen for all curves as this represents a system condition which is in general usable, but approaching overload.

The loading possible in private radio systems is bracketed by the curves of average message length between 10 and 25 seconds (actually closer to 10). In contrast, the telephone loading is forced to follow a curve somewhere between average lengths of 100 and 250 seconds (closer to 250). Note that the single channel load in the private radio case is

about 50% while for the telephone system it is approximately 5%. Since an ideal theoretical load is 100%, the maximum theoretical improvement due to trunking any number of channels in the private radio case is 2:1 and for the telephone case is 20:1. Note the potential benefit for common carrier telephone use of trunking is 10 times that of the potential for private land mobile radio use.

In a trunked radio system there are a number of important factors not considered in the above quantitative results. These factors which are considered individually later are:

1. signalling time losses,
2. geographic inefficiency,
3. effect on peak capacity,
4. human factors.

3.3.5 Effect of Signalling Time

In a radio trunking system some form of automatic switching system is needed for control of the multi-frequency radio system. This system, commonly called a supervisory system, performs the function of finding an available channel, capturing the channel, selecting the intended receiver and eventually terminating the call by releasing the channel. In order to accomplish this, the supervisory system requires a certain amount of data communication between the mobile and the central station. The air time required on the radio system represents a loss in available air time for the human message. Therefore, it must be subtracted from the total air time to find channel efficiency. With the very short message common to private radio, it is obvious that as little as one or two seconds spent in signalling causes a significant loss in efficiency. With a ten second message, for example, two seconds of signalling represents a 20% loss in efficiency.

The amount of time devoted to signalling depends on the specific system design and particularly the data rates used. It should be noted that a mobile channel because of vehicular "flutter" and the high man-made noise environment (particularly ignition noise) is not well suited to high speed data transmission. Supervisory system signalling must have a reasonably high level of reliability as errors can cause a variety of system problems which could lead to interference and greater inefficiency in spectrum utilization. In order to permit an estimate of the effect of signalling time on efficiency, a system model was devised and analyzed. The users served are those who need communication only among their own members, with no need to signal into the land telephone network. Signalling rates and techniques such as marked idle channel operation were assumed similar to those used in the IMTS system. The net amount of signalling time was much less than current IMTS operation, since less information is required and fully automatic signalling has been assumed. Signalling times of the model system ranged from 1.39 to 2.94 seconds depending on the number of channels and population of users. This compares to typical IMTS signalling times with manual dialling of a seven digit number of 25 seconds or more.

The results of this analysis are presented in Figure D7. Note the curves for typical private message lengths are much lower than in Figure D6. Note also that efficiency does not increase monotonically with an increase in channels trunked, but that it actually falls off rather drastically due to increased signalling traffic and queues building up in the signalling system.

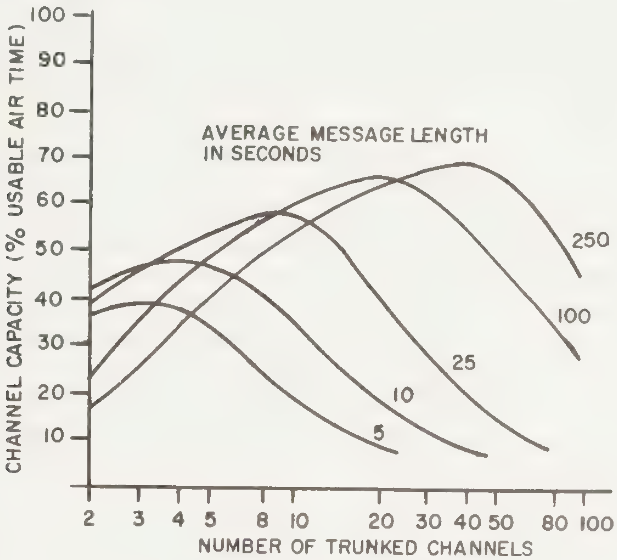

Fig. D7. Trunking efficiency.

The maximum efficiency (channel capacity) achievable for 10 second average message length is 48% which is actually less than can be obtained in busy single channel private systems and better than 2:1 less than the maximum theoretical capacity of trunked systems with unlimited numbers of channels. Thus a figure of 1/2 can be used as the best case loss due to signalling time losses.

Note this factor of 1/2 is really due to a combination of signalling loss and limitations of a practical system and access criteria since the reference is the assumed 100% capacity of a theoretical system. The 100% capacity theoretical system would have zero signalling time and either an infinite number of channels or infinite allowable access delay.

3.3.6 Geographic Inefficiencies

A trunking system servicing groups of users must provide radio coverage of the combined service areas of all users in the group. In contrast private systems need cover only their own service areas. This leads, in the former case, to a waste of potential geographic isolation between users which could otherwise permit simultaneous use of frequencies.

Practically speaking a trunked system would have to cover an entire metropolitan area. In this area, a given frequency could be used only once. Private radio users, however, in many cases obtain simultaneous use of a frequency in a metropolitan area. For example, a taxi company or a delivery service operating in a northern suburb of a city can use a

given frequency at the same time that a southern or western based company would use it. This is possible whenever the prime service areas of distributed radio systems do not overlap, such that tolerable co-channel interference results.

In one example, a group of high band taxi companies obtained better than three times the usage which could ordinarily be obtained if the frequency were used only once within the area. If these users are grouped and serviced by a trunking system, simultaneous use would be prohibited by the supervisory system. In this case a 3:1 decrease in efficiency would result.

The principle here is that, as a system is expanded to service many users, it must cover the combined service areas of all users. This factor may completely over-shadow any gains which might otherwise be made through trunking. In the study quoted, a 3:1 factor was measured. This decreases to unity if coverage of the entire metropolitan area is required by all users in the system. For the average of all private systems, the geographic factor would be somewhere in between, perhaps a 2:1. Thus a loss factor of 1/2 will be assumed in later calcualtions.

3.3.7 Peak Capacity

It is important to view a group of channels, not only with regard to average delays, but also from the point of view of total peak capacity.

When a snowstorm or rainstorm hits and traffic is snarled, communication to the mobile fleets of almost all users peak. A ten channel trunked system can only carry 10 simultaneous conversations. The peak capacity is fixed and cannot be increased by trunking. In fact, the peak capacity is decreased because the signalling time subtracts from usable air time.

The theoretical results presented earlier assume random arrivals of calls for service and independence of the demand in each channel. Capacity and access criteria are based on average statistics. In practice,channel capacity in terms of the number of users able to use a given frequency may be more limited by the peak capacity of a channel and peaks may in fact show correlation, such that the ability to distribute load in real time is of no value. For example, in police communications, major disasters cause an abrupt rise in communications load on all channels at the same time. To the extent that this is the limiting factor, a net loss in peak will result due to air time lost to signalling. In the model system studied, the net loss in peak capacity for a 10-channel police system would be 22% based on a 2.84 second signalling time and 10 second average message length. For a 100-channel system, the loss in peak capacity would be 28%. A reasonable assumption then for a loss factor due to peak capacity reduction would be 1.25:1. It should be noted at this point that this is a lower bound,in that the problem of queue build-up in the signalling system has been disregarded.

3.3.8 Human Factors

One of the major differences between trunked and non-trunked radio systems lies in the area of the method by which the channel is organized. As previously discussed, the supervisory system in a trunked system controls the initiation and termination of calls. In distributed private systems this is left to the individual operators, i.e., the channel is self-organized rather than automatically controlled. The appearance of these systems to an operator is quite different as is his reaction and motivation toward efficient use of the channel.

In a self-organized radio system, the users are direct participants in the action and can adapt to conditions in a variety of ways. In contrast, the user of an automatic (trunked) channel, like a telephone user, has very little exposure to the message traffic and tends to treat the system as having unlimited capacity until the system breakdown through overload. He also feels very little pressure to limit his message length since he knows that the channel has been automatically blocked to other users, no one hears him, and under no circumstances can they capture the channel from him. The channel, once secured, is protected during even long pauses in the conversation.

In contrast, in the self-organized private system, users are monitoring conversations and even a moderate length pause between push-to-talk keys is likely to result, during busy periods, in another user capturing the channel for a brief exchange. This psychological pressure also causes him to be more attentive and respond more quickly when a channel does open up. The private user also exhibits a number of adaptations which tend to increase busy hour capacities, such as; (1) speaking more rapidly, (2) reducing the less-essential content, such as shortening salutations, etc.

Over a period of time the user learns to; (1) defer more routine business to less busy times, (2) use prearranged codes, such as the "10" code to shorten messages, (3) recognize distant users with whom he will not interfere and capture the channel in his local area, (4) enforce communication discipline in terms of the types and frequency of messages to be handled by radio, that is reduce his overall communication load.

The quantitative effects are difficult to measure. One of the few pieces of factual data available is the study by IITRI of a police radio system in which average message lengths during a busy hour were found to decrease from 8.31 seconds to 6.14 seconds or by 26%. This is just due to the message shortening alone.

In a recent paper "Public Safety Trunking", in November, 1968 Communications, Daugherty and Kelly have estimated the increase capacity due to adaptation in "dispatcher dominated" police systems as a 2:1 factor. This figure is used in the following calculations.

3.3.9 Calculation of Overall Trunking Efficiency

Having obtained quantitative estimates of these various factors, we can now estimate the net capacity of a trunked radio system applied

to provide a general mobile radio service. Figure D8 shows that, by applying all of the factors as discussed, the result is a net of only 1/4 the usable capacity for trunked channels as compared to an equal number of private radio channels. This results from a theoretical trunking improvement of 2:1 followed by the application of three factors, each of which is sufficiently large to negate the theoretical efficiency of trunking for the short message land mobile radio systems.

$$\begin{array}{l}\text{Relative}\\ \text{Trunked}\\ \text{Channel}\\ \text{Capacity}\end{array} = \left(\begin{array}{c}\text{Theoretical}\\ \text{Trunking}\\ \text{Improvement}\end{array}\right)\left(\begin{array}{c}\text{Access}\\ \text{And}\\ \text{Signalling}\\ \text{Time Loss}\end{array}\right)\left(\begin{array}{c}\text{Geographic}\\ \text{Inefficiency}\end{array}\right)\left(\begin{array}{c}\text{Human}\\ \text{Factors}\\ \text{Loss}\end{array}\right)$$

$$= (2) \quad (1/2) \quad (1/2) \quad (1/2)$$

$$= 1/4$$

Based on average access delay of 10 seconds.

Fig. D8. Relative capacity of trunked channels compared to single channels.

For specific service such as police, taxi, etc., each of the factors in the equation could be estimated to arrive at a calculated value for that specific service.

If we were to consider that the channel capacity is limited by peak capacity rather than average delay, we find the results shown in Figure D9. In this case, the starting point for the theoretical peak capacity of a trunked system is unity or the same as the non-trunked channels. The various factors are then applied which reduce the peak capacity to 1/5 of that obtained by separate private systems.

$$\begin{array}{r}\text{Relative}\\ \text{Trunked}\\ \text{Peak}\\ \text{Capacity}\end{array} = \left(\begin{array}{c}\text{Theoretical}\\ \text{Trunked}\\ \text{Peak}\\ \text{Capacity}\end{array}\right)\left(\begin{array}{c}\text{Signalling}\\ \text{Time Loss}\end{array}\right)\left(\begin{array}{c}\text{Geographic}\\ \text{Inefficiency}\end{array}\right)\left(\begin{array}{c}\text{Human}\\ \text{Factors}\\ \text{Loss}\end{array}\right)$$

$$= (1) \quad \left(\frac{1}{1.25}\right) \quad (1/2) \quad (1/2)$$

$$= 1/5$$

Fig. D9. Relative peak capacity of trunked channels compared to single channels.

3.3.10 Existing Channel Loading Comparisons

The only existing radio trunking system operating under LMRS conditions is the IMTS system developed by the Bell Telephone. It is interesting to compare the loading obtained in this system with that currently obtained in heavily loaded private systems. Figure D10 shows the results.

SYSTEM	NUMBER OF USERS	MOBILES PER FREQUENCY	RELATIVE LOAD
CHICAGO IMTS 8 Duplex channels	400	25	1
CHICAGO BUSINESS SERVICE (150 MHz Band) 12 Simplex channels	1854	154	6.2
CHICAGO TAXI SERVICE (150 MHz Band) 7 'Two-Frequency' channels	1844	132	5.5

Fig. D10. Comparison of existing channel loading in private and common carrier systems.

The maximum design loading for the eight channel IMTS system is 480 mobiles. The estimated loading in Chicago, which is considered heavily loaded, is 400 mobiles. On a per channel basis, this amounts to a current loading of 50 mobiles or 25 mobiles per frequency, since these are two-frequency channels.

In comparison, the Chicago Area Business Service in the 150 MHz band has 12 channels with a total of 1,854 transmitters or 154 transmitters per frequency, this amounts to approximately a 6.2:1 ratio.

Similarly, in 150 MHz band taxi service, we find 1,844 mobiles in seven channel pairs. This amounts to 263 mobiles per pair, or 132 mobiles per frequency. This is a 5.5:1 ratio in favour of the private systems over the only existing trunked common user systems.

3.3.11 Cellular Systems

In theory, geographic isolation can be combined with trunking in cell organized systems. Multiple use of frequencies can then be obtained with short range transmissions within each cell. It has been suggested that cell sizes as low as one mile square would permit very large system capacities.

Unfortunately, such a system suffers from two major flaws. First, the system would be extremely complex, and second, a large amount of spectrum would be required for the expanded data communications required in the supervisory system which must add the following functions to those previously discussed:

1. Vehicle location to select the correct cell for calls to a vehicle,
2. Cell identification to the vehicle for calls from a vehicle,
3. Real time switching of cells and frequencies during a conversation as a vehicle crosses boundaries.

It should be remembered that expressway traffic could allow a mobile to pass through cells at a rate of one per minute. The problem of rapidly updating the information regarding location of mobiles will require significant spectrum as well as considerable cost and complexity. The number of data channels required for supervisory control functions can exceed by more than an order of magnitude the voice channel capacity being controlled. The cost, complexity and signalling requirements are enormous.

3.3.12 Conclusions

It is apparent from the above discussions that the trunking concept does not represent a useful solution for the growing frequency congestion in the Land Mobile radio services. Trunking applied to these services would result in a substantial loss in flexibility to meet individual user needs, would result in a substantial decrease of efficiency of spectrum utilization because of factors peculiar to the nature of private radio systems as compared to telephone service.

This is not to say that trunking is not a useful concept where long person-to-person messages predominate. Such usage is typical of mobile telephone systems such as the IMTS system which is really an extension of telephone service into a mobile. Here, the very long messages combined with lower communicator skills which preclude adaptation and the need to fully interconnect with the line system, dictate the use of trunking. In fact, without trunking, low channel usage of poor service would be unavoidable. With trunking,the very unique capability of automatic dialling of the full land telephone plant is provided for those who require this capability.

3.4 SHARED COST SYSTEMS

One objective of our technological advance is to bring mobile radio communications to the largest number of enterprises that can benefit from it. This can only result in increased productivity and enhanced service to that segment of the population served by these enterprises. In some cases, the economic benefits to the user are such that the capital cost of a base station and a small fleet of radio equipped vehicles (say five units) can easily be justified. Such a small system, however, would have need for only a small proportion of available air time and a clear channel in an urban area would not represent good spectrum utilization.

There would be other cases where the benefits could not pay for the full cost of the base station installation. This is particularly so because of higher costs of UHF equipment.

A solution to the first problem is co-channel assignment with each enterprise having their own base station.

A solution to the second problem is the shared-cost system where one base station or repeater is used by several enterprises with costs apportioned and channel usage maximized. There may be several dispatchers in such a system with each one selectively signalled using coded squelch. Similarly, coded squelch in the mobiles minimizes chatter from co-channel users.

The base station or repeater may be owned and operated by the users on a cost sharing basis or by the equipment supplier who charges base station costs to the several users on a non-profit basis.

Even if economics supported co-channel users with separate base stations, there is a distinct advantage of having a common base or repeater.

The RF interference between co-channel users would be eliminated. The common base or repeater of course is for people who need to cover the same geographic area.

This type of system is in widespread use and the technique, as an aid to spectrum conservation, is well established. Future technology will be directed toward improvements in signalling to improve privacy between common users.

3.5 MULTIPLEX

A serious case has been made for the use of multiplexing as a means of more effective utilization of the spectrum. Although it is well known that multiplexing techniques offer certain advantages in a point-to-point system, objective analysis shows that for the Land Mobile Radio Services the penalties associated with its use far outweigh the advantages.

The following is a list of exceptions and practical considerations that must be understood in relation to the use of multiplex techniques for the Land Mobile Service.

3.5.1

A multiplex system requires conventional means for mobile to base communications and, therefore, is applicable only to the base to mobile communication path.

3.5.2

A careful analysis of the 12-channel multiplexed system shows a transmitter power penalty of 450 to 1 and 2,000 to 1 for a FM/SSB and FM/FM system respectively. This power penalty is based on the power required for an existing 5 kHz deviation single-channel system to communicate the same distance.

Figure D11 is a meaningful presentation of these considerations. Although the transmitter power penalty might seem excessive, it is based on the known fact that the signal-to-noise in FM systems is proportional to the square of the modulation index.

3.5.3

As modulation index is proportional to the reciprocal of the highest modulation frequency, it is inherent that multiplex systems will suffer. Thus, whereas existing systems because of building shadowing, ignition noise and flutter require 25 to 100 watt transmitters to maintain the required range, multiplex systems would require 45,000 watt FM/SSB and 200,000 watt FM/FM transmitters to be equivalent to twelve 100 watt single-channel transmitters.

3.5.4

Because of the extremely high power levels required for the FM/SSB system, the signals appearing at the input of every receiver will now be 27 dB stronger. A result of this will be that all interference products generated in the front end of receiver, such as intermodulation and mixer spurious, will be significantly increased. For example, the intermodulation product will increase by three times or 81 dB and higher order mixer spurious products will increase even more. The case of FM/FM systems would result in products that are 99 dB higher.

It is interesting to project what this increase in interference means to existing systems. Using system intermodulation theory, each of the interfering bases would have to be moved by a path loss factor of 18 dB from the interfered mobile receiver in order to maintain coverage in this area. Although the total number of bases will be less in a multiplexed system, their individual carriers are always present so that these interference areas are locked out 100% of the time. To recover this area would require either multiple frequency mobile assignments geographically spaced or severe geographic spacing of allowable adjacent channel usage. Using plane earth path loss calculations results in a distance increase of three. That is, all bases must be separated from each other by an additional factor of three, or a potential area loss of nine times. Either alternative results in a loss of spectrum efficiency.

Base-to-base interference in a block-allocated multiplex system is even worse. The base receivers that are assigned to the band edges will be receiving other large base signals as well as the normally small mobile signal. This situation is acceptable today because of the large differences in power of the two systems. As base-to-base interference is more normally line-of-sight, the interference product will be much greater than the 81 dB computed for the base-to-mobile path. The only solution would be a significant increase in the guard band between the base and mobile frequency blocks or a drastic reduction in spectrum efficiency.

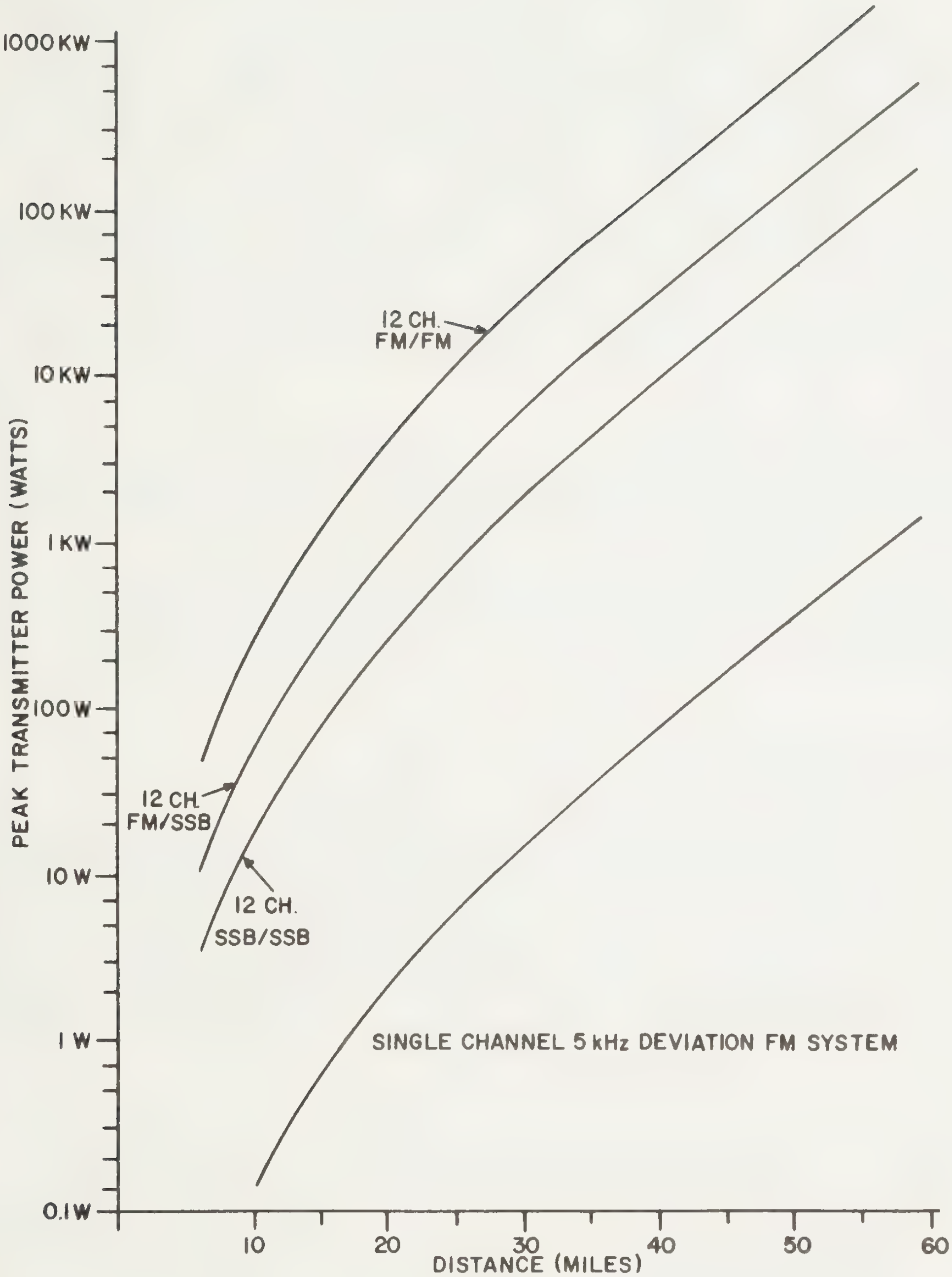

Fig. D11. Required peak transmitter power to provide 12 dB S/N at received output at 450 MHz.

3.5.5

Assumption is often made that channel spacing should be equal to twice the sum of the deviation and the highest audio frequency. This formula however, is not applicable to low modulation index systems, such as one having 5 kHz deviation and three 3 kHz audio system. The resulting 16 kHz would be prohibitive in side band splatter. In microwave multiplex systems the formula provides for the "necessary bandwidth". This implies that the energy contained in this bandwidth is the minimum necessary for faithful reproduction of the received sub-channels. In a practical system the receiver filter must have a significantly wider bandwidth than the "necessary bandwidth". It is common practice to allow a 2 to 1 factor for realistic filter design to account for filter phase and amplitude non linearities. In other words a multiplex system that allows for practical filter design must have an increase from 39 to 53 of the Spectrum Requirement Index for the FM/SSB system, which is a spectrum loss of 6%, rather than 22% which might have been expected.

3.5.6

An SSB/SSB system suffers from all the drawbacks mentioned earlier of simple SSB operation in the VHF/UHF bands, e.g., stability, poor impulse noise performance, flutter, etc.

In summary, increases in spectrum efficiency for multiplex systems do not exist because of the realities of filter design and/or the nonlinear interference degradations due to the large powers necessary to maintain range.

3.6 SELECTIVE DEVICES

With the crowding of the land-mobile spectrum, adjacent channel selectivity and receiver front-end selectivity has increased in importance. As a result, the art of crystal filter design has recently advanced very significantly. An RF crystal filter is now available which has 17 dB selectivity on the adjacent channel in the high band. These filters are essential to multi-channel mobile telephone radio equipments or in other applications where adjacent channel operation is necessary in the same location. These crystal filters are also useful in combatting receiver intermodulation problems.

Titanate ceramic resonant elements have been commercially available for some time and have found application as IF bandpass filters. Another device recently announced is the mode-coupled monolithic crystal filter for improved IF selectivity. Four such filters collectively exhibit a sharp skirted bandpass characteristic and do not require tuning adjustment.

There have been steady advances in the technology of selective devices for application external to the radio equipment. These developments are mainly in the area of bandpass filters or multi-couplers to enable the sharing of one antenna by many transmitters and receivers.

In the years ahead attention will continue to be directed toward improvements in selective devices and we will see integrated circuit technology employed in new ways to make tenable the spectrum we already have.

3.7 COMPUTERS FOR GEOGRAPHIC ALLOCATION

Through a careful analysis of the service areas required by various users, it is possible to determine the feasibility of assigning the same channel at several locations within the same metropolitan area.

By means of coded squelch signals and making maximum use of the FM capture effect, then the mobiles close to one base station could operate without serious interference from the other base station(s).

For example, the municipal vehicles of one borough could share a channel with a second borough as neither are likely to operate beyond their own boundaries.

As frequency crowding in urban areas increases, geographic sharing could become more prevalent as it has in large cities in the USA. To minimize interference, optimum selection of locations and channels must be made from a wealth of information which could readily be stored in a computer. It follows that the computer can also be used in geographic assignment of tertiary channels (the so-called 15 kHz split-split) using a program which allows closer separations than necessary with co-channel operation.

The computer may be used on other problems related to frequency assignments. One of these is intermodulation analysis in which all the transmit and receive frequencies in a given area are examined to determine the probabilities of generating interfering IM products. This practice is in use now and will require refinement in the years ahead to speed up the selection of a suitable channel.

Ultimately, the high band must go through an evolutionary change of channel assignments so that the advantages of spectrum utilization through pairing can be realized. A computer will be of value in this procedure as well.

Future technology will involve further work in software so that the program more nearly fits the real life situation in the field.

3.8 MULTI-RECEIVER PICKUP

The purpose of a multi-receiver pickup system is to increase the range of mobile or portable equipment whose output power is usually less than the base station transmitter. By strategically locating individual receivers throughout the urban area the talk-back and talk-out range can be equalized.

A voting system is almost synonymous with the multi-receiver system to ensure that only the receiver having the best signal-to-noise ratio is connected to the land based party to the conversation. Multi-receiver systems have found application in mobile-telephone usage and are now being used to extend the talk-back range of low powered, hand carried, two-way radio equipment used in other services. Because of the low power, interference generating capabilities are minimized and, in this respect, the system aids spectrum conservation.

Improvements in the voting system hardware will be the direction of future technology as recent improvements in portable products has accelerated the demand for them.

3.9 TRANSMITTER SYNCHRONIZATION

Just as multi-receivers will extend the range of portable transmitters, multi-transmitters will extend the range of portable receivers such as those used in radio paging. In order to ensure continuous coverage of a metropolitan area, it is necessary to place the transmitters so that generous overlap areas occur giving rise to interference problems. When a mobile radio receiver receives simultaneous signals from two co-channel transmitters, an interfering beat-note is detected with a pitch equal to the difference frequency between the two transmitters. With frequency stability elements common to land mobile equipment, the pitch of the interference varies widely with time and temperature and renders the system unacceptable.

Some systems transmit the same message sequentially on the two transmitters. This cuts in half the capacity of the system and is impractical where larger numbers of transmitters are required.

Recent technology has given us high stability oscillators which enables frequency control to within a few cycles per year and permits multi-station operation with minimum interference internal to the system. Synchronization of the transmitters from a common source has been proposed and in due course may be available commercially.

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NOTE: This is an abridged summary version included with the Study for purposes of comparison between views on the development of communications technology in Canada and in the USA.

APPENDIX E

A SURVEY OF TELECOMMUNICATIONS TECHNOLOGY*

CONTENTS

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* Precis of Staff Paper One (President's Task Force on Communications Policy, Washington, D.C.) by Eugene V. Rostow.

I. INTRODUCTION

A. The Range of Opportunities

1. Expanding video services.
2. Providing data processors with adequate communications services.
3. Producing terminal equipment which will provide access to computers for households and small businesses.

   Paper tape and card punching equipment, teletypewriters, and visual display terminals number about 200,000 today, and are likely to increase tenfold within a decade.

4. Cost reductions are essential in exploiting these opportunities.

B. Prospects for Innovation

1. While the cost of sending large amounts of information long distances is falling rapidly, the outlook is less favourable for dramatic cost reduction elsewhere.

   As a result, the investment cost of adding a circuit mile of long-haul transmission facilities to the Bell System, which averages $11.00 today, will be about $1.50 in 10 years.

   But long-distance transmission represents a small fraction (about 17%) of the total cost of the telephone network, while switching (45%), terminals (23%), and local loops (15%) account for the rest.

   Data processing capacity has been falling in cost 50% every two years.

2. A dedicated network for data processing may offer cheaper communication and greater flexibility.

   In the 1970's, however, it may be practical to establish either a separate digital network or a subnetwork for data customers within a shared system.

   — by-passing the expensive multiplexing and routing facilities of the basic telephone network.

3. While data terminals will remain costly, the touchtone telephone instrument will offer occasional users direct access to computers.

C. Implications for Policy

1. Data communicators require a wide choice of services and the freedom to establish sub-networks as needed.

2. Depreciation keyed to economic life would permit investment decisions to take into account the impending availability of new technologies.

3. Cost reductions are most needed in local loops and terminals.

II. THE COMMON-CARRIER NETWORK

A. The Focus of Our Analysis Is the Four Elements of the Common-Carrier Network: Transmission and Switched Facilities, Local Loops and Terminals.

Today, 93% of the long-distance telephone transmission plant consists of coaxial cable and microwave facilities. Twisted pairs of wire, however, are still the primary medium for the carriage of signals between local exchanges and telephone terminals. In the more distant future, newer facilities such as millimeter wave guides and laser systems may come into use where routes with densities of around 100,000 cir-circuits are required.

The millimeter wave guides, which in the 1980's may provide guided transmission in the range above 10 GHz are planned for routes of 260,000 voice circuits.

From the L1 to the L3 to the L4 cable systems, voice circuit capacity has increased from 2,000 to 16,740 to 32,400 voice circuits, while annual costs per circuit mile have fallen from $3.00 to $1.50 to $0.90. The L5 system, scheduled for introduction in the mid 1970's will provide 81,000 voice circuits at an annual cost of about $0.35 per circuit mile.

III. TRANSMISSION

C. Spectrum Availability and Maintenance Cost Limit the Economies of Scale Achievable by Microwave Relay Systems.

The newest add-on system, the TH-3, can double (12,000 to 23,000 voice circuits) the capacity of existing microwave installations at much less than the cost of duplication ($2.75 vs $4.15 per circuit mile).

D. The Cost of Satellite Circuits Are Expected to Decline Sharply by Mid-1970's.

The current generation of standard two-way INTELSAT earth stations cost between four and six million dollars each. During the 1970's, however, increased satellite power will permit the introduction of earth stations with smaller (e.g., 30 ft.) non-tracking antennas and uncooled receiver amplifiers that will nevertheless provide the same number of circuits per unit bandwidth. Earth station costs are likely to drop to less than $500,000 i.e., by a factor of 10.

F. Digital Transmission Techniques Offer Superior Signal Quality and Interference Protection, Particularly on Long Routes and for Radio Systems.

G. For U.S. Domestic Services, Paired Wire is Likely to be the Dominant Mode on Fixed Capacity Routes of Fewer than 500 Circuits; Microwave Between 500 and 15,000; Coaxial Cable Between 15,000 and 80,000; and Wave Guides Above 80,000.

Taking into account this growth in volume of traffic, Bell has predicted that by 1980 then 90% of its long-haul circuitry will be in coaxial cable, which means that only a small number of circuits will use relatively high-cost transmission media of fewer than 10,000 circuits. According to Bell, the average incremental line-haul investment costs per voice circuit mile will drop from $11.00 to about $1.40.

Fig. E1 indicates the relative costs of different transmission media as the length and circuit density of trunk groups change.

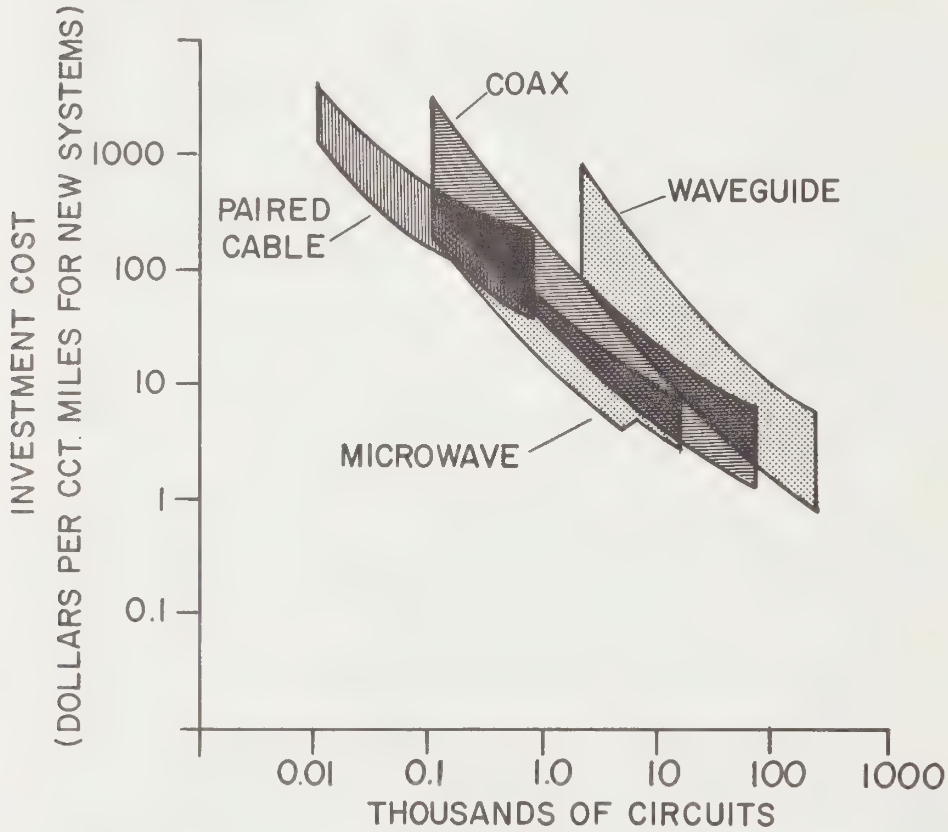

Fig. E1. Cost trends in terrestrial transmission.

H. Domestically, Communication Satellites Appear Most Economical for Wideband Distribution Services and for Specialized Networks Requiring Many Variable, Low-Capacity Routes.

I. On Intercontinental Routes, Communications Satellites Are Likely to Become the Dominant Mode by 1980.

IV. SWITCHING

B. Progress in Circuit Switching Has Brought Direct Distance and Automatic Dialling and Has Increased Switching Speed.

Switching's share of total investment in the telephone system is relatively low (28%), but operator salaries raise its contribution to the cost of the average telephone call to 45% and, in the case of long distance calls alone, to 54%.

Present-day space-division switch that can handle 10,000 terminals is about three times as costly as one accommodating 2,000 terminals. Time-division switching has scale efficiencies not present in space-division equipment; thus its projected savings through size may be much greater. Circuit switching also has scale economies at the toll exchange level. The cost per trunk of a 16,000 trunk switch is half that of a 3,000 trunk switch; in the future 50,000 trunk switches are expected to provide still lower costs per trunk.

C. A Digital Network, Using Time-Division Switches, May Reduce Modulation, Switching, and Multiplexing Costs for Data Communications.

The accompanying table based on technology expected to be available within 10 years, compares the investment costs for data users of an analog system (with space-division switching) and a digital communications system (with time-division switching).

TABLE 1

Network Cost Comparisons Per Customer

Function	Analogue Network		Digital Sub Network Highest		Lowest
Conversion of digital signals	$500		$ 0		0
Local distribution	$256	(1-1/10)	$ 292		292
Local switching	$184	(1/2)	$ 92	(1/3)	37
Toll switching	$ 25	(1/2)	$ 12	(1/3)	5
Trunking (terminal)	$ 50	(1/3)	$ 17	(1/10)	5
(line-haul)	$ 50	(1-1/10)	$ 55		55
Total	$1065		$ 468		394

The principal obstacle to a digital, multi-purpose network, serving inherently analog (voice, TV, etc.) as well as inherently digital (data) customers, is the cost of converting

analog signals into digital form for transmission over the network. Today the necessary equipment would cost about $1,500 per subscriber. Optimistic predictions for the mid-1970's, based on mass production of large-scale integrated circuits, place the cost at perhaps only $50.00 per subscriber. In the 1970's the number of data terminals on the network is not likely to exceed two million.

D. Computerized Store-and-Forward Switching Is More Costly Than Circuit Switching. Therefore, Message Systems Will Generally Store and Forward Only Messages for Which Circuit Switching Is Unsuitable.

V. LOCAL LOOPS (DISTRIBUTION)

A. Broadband Loops, Installed for Cable Television, Could Carry Point-to-Point Traffic as Well.

It has been estimated that the capacity of a 20-channel video cable could be expanded by 50% at an additional cost of only 20%. Those 10 extra video channels could provide the bandwidth equivalent of 20,000 voice channels, exclusive of frequency spacing to prevent interference.

VI. TRADE-OFFS AMONG TRANSMISSION SWITCHING AND LOCAL LOOPS

A. Because Transmission Costs Are Falling Faster than Switching Costs, Some Intermediate Switching Will Be Avoided by Creating More Direct Routes.

B. Economies of Scale in Transmission and Switching Will Lead to the Construction of Larger Switching Centres.

The per-trunk cost of a 50,000-trunk switch (a projected Bell development in the mid 1970's) is expected to be less than half the per-trunk cost of a 3,000-trunk switch.

IX. TELEVISION DISTRIBUTION

The least costly means of distributing TV signals is the existing method — high-power transmitters and tall antenna towers. It is not discussed in detail for two reasons. First, little change is foreseen in local broadcasting technology over the next decade. Second, it does not appear possible to provide large numbers of TV channels (12 or more) to most viewers through normal over-the-air broadcasting means with the existing industry structure and the lack of available spectrum.

A. Cable Television Is Attractive in Densely Populated Areas Where Cables Need Not be Laid Underground and Where There Are Few Natural Barriers.

Current CATV cables have the capacity to transmit from 12 to 25 simultaneous TV signals, depending on distance and repeater spacing. The estimated cost of cabling 75% of the TV homes in the nation in 1980 (places with above 900 viewer locations per square mile — totalling some 50 million locations) is between $100 and $200 per viewer location or $5 to $10 billion.

The cable cost for given quality goes up as a function of distance and quantity. Sixteen miles is about the maximum distance for today's systems, providing about 200 square miles of coverage. By the late 1970's a 25-mile distance or about 500 square miles coverage may be possible at cost levels close to today's.

B. Millimeter-Wave Radio Techniques May Provide Economical Multi-Channel Primary Distribution.

A system employing frequencies in the 18 GHz frequency range has been developed which will transmit the entire VHF television spectrum (12 channels) simultaneously over distances up to 6 miles, using a 100 MHz bandwidth.

C. The Direct Broadcast Satellite is Cost-Competitive Only for Reaching a Very High Percentage of Television Households from a Single Organization Point.

Based on Figure E2, the least cost system for given numbers of viewers and channels is given in Table 2.

TABLE 2

5-Year Capital Costs — Broadcast Satellite

800 MHz Frequency Region

Viewers (Millions)	1 Channel U.S. Coverage	12 Channel 50% U.S. Coverage	24 Channel 50% U.S. Coverage
1	$ 60	$ 225	$ 315
10	$ 36	$ 93	$ 113
50	$ 27	$ 43	$ 63

The per household costs of the space segment are substantial until the number of homes sharing the cost is large. Moreover, if all TV program distribution were by satellite, the viewer would be required to make an additional investment in a receiving antenna — whose costs are estimated to range from $50 to $300 per location.

Figure E2 shows only launch vehicle cost; the satellite cost normally approaches the launch cost.

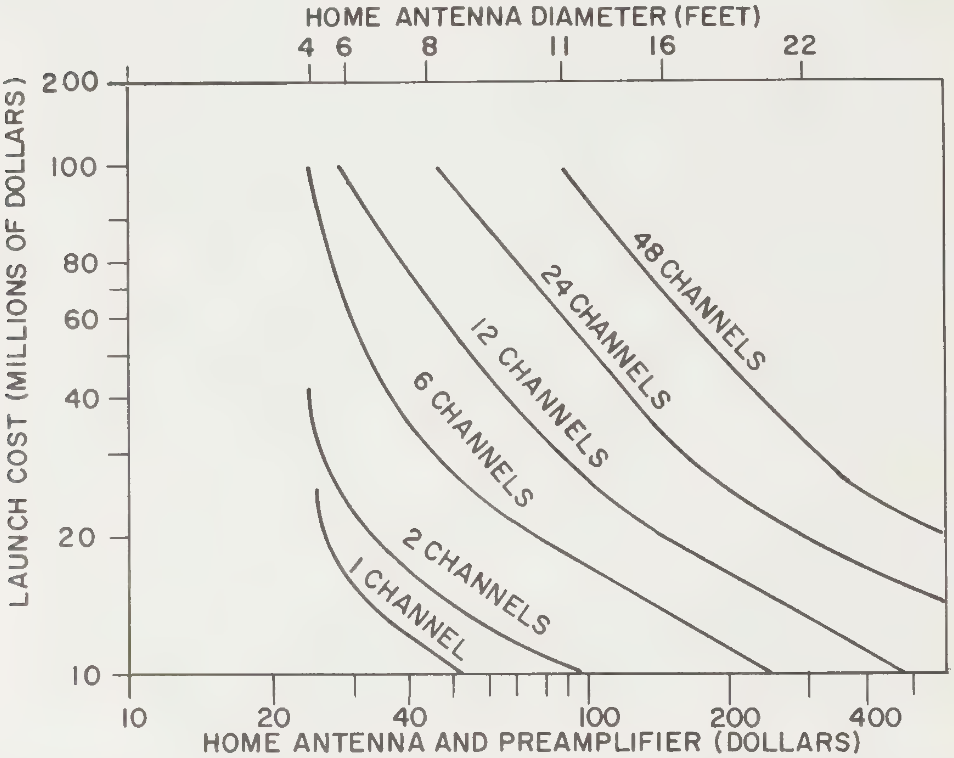

Fig. E2. Estimated cost relationships in direct satellite broadcasting.

X. NEW SERVICES

A. Computer Services Are the Fastest-Growing Market for Telecommunications.

1. In-House and Single-Industry Systems Are Likely To Provide On-Line Data Processing For Customers with Complex Programs.

The annual production of on-line terminals,which stood at 25,000 in 1966, is expected to rise to 100,000 by 1970; and by the mid 1970's half the computers installed annually will probably offer on-line capabilities.

Since the 1950's, computer processing and memory capabilities have been growing 50% cheaper every two years.

Software is the only segment of time-sharing expenses for which no important cost-reducing innovations are in sight. As a result, programming, which now accounts for 50% of the cost of a typical time-sharing system, may reach as much as 80% by the mid 1970's.

If it does, storage capacity for 1,000 characters, which on a representative time-sharing system now rents for $0.50 a month, will be available for less than $0.10

by 1980; and the price of one minute of processing time (about what is consumed during half an hour of on-line use) will fall from \$3.00 to \$0.50 in this same period.

Teletypewriter consoles, now selling for \$2,000-\$7,000, can be expected to cost about 20% to 25% less in 1980 while the price of time on the computer terminal may be cut in half from \$10/hr. to \$5/hr. Specialized terminal devices, e.g., cathode ray tube systems, may sell for one-fourth of the existing prices; or as little as \$500.

2. The cost of computer-assisted instruction will decline significantly over the next decade.

    Thus, by 1980, we can expect machine drill and tutorial software to represent 15% and 33% of the total cost of machine instruction, respectively. Our projected cost estimates (\$45 per student per year for drill material and \$160 for tutorial).

3. Data retrieval systems, with the touchtone phone serving as user terminal, are likely to be the most important household market for computer services.

    The Touchtone telephone, however, with its ability to generate data signals, will make data retrieval services available to mass markets, particularly small business and household users who are unwilling or unable to pay for a specialized data terminal. These Touchtone handsets are likely to be in wide use by the mid 1970's as computer input devices.

    If the television receiver were permitted 30-45 seconds to assemble the picture, the signal could be accommodated on a telephone-grade circuit.

    Perhaps teletypewriters will show a price decline of 25% by 1980, while cathode ray tube terminals may be available for as little as \$500, as compared to over \$1,000 today.

4. Computerized checking account systems are feasible today and might serve a useful function as a non-credit shopping cards.

    Even at current rates the total cost of using the computer to carry out the transaction could be as little as \$0.50 (assuming less than 10 seconds of central-processing-unit time at the computer terminal). The terminal attachment for transmitting the information on the card would rent for about \$5 a month.

B. Broadband Cable Systems Could Bring Entertainment and Shopping Services into the Home at Low Cost.

As discussed in Section V, broadband cables can carry large numbers of video channels at reasonable cost. For example, it is possible today to install an underground coaxial cable with a capacity of 27 television channels at an investment cost of about $96 per subscriber location.

With an installation charge of $15-$25 per household and a $6 monthly fee, an 81-channel system could provide entertainment, educational programming, general information, and shopping services.

For example, the capital investment costs of typical systems of even greater capacity if laid simultaneously would be $155 per location for a 54-channel system and $215 per location for an 81-channel system. In comparison, if the additional channel capacity was installed some time after the first cable was laid, so that the streets had to be torn up a second time, the investment costs would be about $192 per location for a 54-channel system and $250 per location for an 81-channel system.

C. Only Demand for an Extremely Wide Choice of Programming Would Make a Switched Broadband Network Less Costly than a Broadband Cable.

For local service alone (programming would have to be stored in every city) the capital costs for transmission and switching facilities would be about $5,000 per location, implying a monthly rental fee of about $135. Because average household expenditures on television facilities (including receivers) is not expected to rise above $184 a year by 1980, there seems little chance that one-way switched broadband systems will provide viable commercial services in the near future.

E. Video Telephone Costs, over the Next Decade, Are Likely to Exclude All but a Limited Business Market.

Picturephone is another important new telephone service planned for user terminals by the late 1970's. Bell's own projection is that by 1980, only 1% of its customers will be subscribing to Picturephone service.

A Picturephone terminal will consist of a 5" square monochrome television screen, a small television camera, and knobs for varying the camera's range, brightness, etc. With a million customers, the installed cost of a Picturephone terminal will be about $1,000 (compared to $50 for a telephone handset) in 1980.

Because video telephone pictures will have fewer scan lines than a television picture, its bandwidth requirements will be smaller; i.e., about 1 MHz. If Bell's estimate is correct and 1% of its locations subscribe

to Picturephone by 1980, this service alone will account for twice as much circuit capacity as all the voice telephone service now being provided in the Bell System. As a result, the transmission and distribution costs attributable to a Picturephone terminal will be about 10 times the cost of equivalent service for a voice terminal. Picturephone switching, per se, will only be twice as expensive.

The monthly terminal rent, covering a line to the local exchange as well as the station set, is estimated at \$100. Average monthly toll charges should be about \$30. A New York-Washington call, for example, would cost about \$7.00.

TELECOMMISSION

Study 4(b)

Research and Development Policies and Programs

The Department of Communications

TELECOMMISSION STUDY

4 (b)

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This Report is to be considered as a background working paper and no effort has been made to edit it for uniformity of terminology with other studies.

Telecommission Study 4(b)

Table of Contents

Telecommission Study 4(b)

Research and Development Policies and Programs

Introduction

This report has been organized into two general investigations, one quantitative and the other qualitative. The quantitative part which is contained in Chapter 1 consists of an examination of the level of research and development (R&D) activity in the communications sector in Canada. Communications and particularly telecommunications is perhaps unique in that there is a high level of activity conducted in the universities, by industry and by government. R&D expenditures as a percentage of total sales of manufactured products is perhaps higher in the telecommunications industry than in any other secondary manufacturing field in Canada. Our study suggests that this is the result not only of the structure of the industry, with the relatively few and vertically integrated groupings in the telephone field, but also results from the accumulated expertise particularly of that part of the industry utilizing electronics technology. It also reflects the very high rate of change and development which has taken place in the sector.

The qualitative portion of this study which is covered in the last four chapters of the report constitutes an attempt to appraise the effects of R&D and to judge whether current policies and programs are adequate or contributing effectively to the development of both scientific knowledge and Canadian industry's capacity to maintain a high technological level of competence in the communications field. To specialize, even to focus particularly on one sector, was difficult but offsetting this difficulty was the constant realization that generalization by the Project Team would result in very shallow findings when compared to the scholarship that has gone on in this field in Canada in recent months. The Project Team was aware of the work undertaken by and for the Science Council of Federal Government in the Support of Research in the Canadian Universities. Many of the members of the Project Team had participated at various levels of the work of the committee of the Senate investigating science policy (Lamontagne Committee) and there was at times a feeling that perhaps too much has been added to the rhetoric of science policy and not enough emphasis has been placed on the examination of the mechanics of its implementation .

During the course of the discussions which resulted in the drafting of this report there was a recurring debate as to the relationship between R&D and the fabrication of new products for telecommunications systems. At various times it was suggested that the key to development was not research but innovation or perhaps more properly the economics of applying

technology which is available. While there was no profound examination of the innovative cycle as it applied to the communications sector, the TCTS representative suggested that the organization and structure of an industry had a great determination on the ability to innovate and apply new technological processes. In the final analysis there was no clear cut consensus whether the fruits of research were either predictable or whether the level and activity of research could be accurately related to the product cycle of any industry dealing in communications products or services. Like many other study groups this one was left with the enigma of not knowing whether research results can be optimized through planning or whether its creative aspects leave it essentially a non-predictable happening.

Notwithstanding the large caveat on the certainty of the pivotal role of research and development in the production cycle, the Project Team did take a look at future requirements. This was done with the realization by the members of the group that companies in the communications sector must be technologically competent and, if they are to remain competitive, must also be able to anticipate technological change. Technology is global and the competition is not confined to a supplier's domestic or protected market. To this point research and development activity has to some measure been able to aid in the anticipation of technological change. There was some suggestion that other dimensions in addition to technological research and development must be isolated and analyzed by decision makers if there is to be accurate evaluation of future requirements for communications services.

Chapter 1

A Review of Present Communications Research and Development Activity in Canada

1. Research and development in communications in Canada is a multi-million dollar business. It is estimated that total activity in 1969 was in excess of $94 million. Precise figures are difficult to obtain because of problems of definition, competitive security, and lack of current information. However the following is a reasonably well informed estimate of the situation.

A rather broad definition of research and development relevant to communications is used; in general it includes any research for which a potential telecommunications application can be foreseen, even though the application may not be immediate. It also includes research into devices and techniques that may be used in telecommunications systems or equipment.

1.1 The level of communications R&D activity in Canada

1.1.1 Government - supported research and development

The government supports communications R&D in government laboratories, in industry and in the universities.

1.1.1.1 Intramural

The bulk of the in-house government R&D is provided by the Communications research Centre of the Department of Communications. The CRC has an annual budget of about $7.5 million for in-house research, and about $4 million for contracts (primarily spacecraft development). The main areas of research are Communications, Satellite Technology, and Research supporting Radio Spectrum Management (see appendix A for details).

1.1.1.2 Grant programmes to industry

There are several categories of government aid programs that foster research and development in communications; Defence Industry Productivity (DIP), Program for the Advancement of Industrial Technology (PAIT), Defence Industrial Research (DIR), Industrial Research Assistance Programs (IRAP), and Industrial Research and Development Incentives Act (IRDIA). Under these programs the industrial recepient is usually required to make a contribution at least equal to the government grant (see appendix B).

In 1967, the last year for which information is reasonably complete, approximately $82 million in communications research and development was carried out in industry. For that year, government grant programs paid for some $22 million worth of the work and government contracts for about $4 million. It appears that the 1969 figures will be approximately the same as those for 1967.

These figures are expected to be accurate to about 10%. (see appendix C)

1.1.1.3 Grants to Canadian universities

The major granting agencies are NRC and DRB; additional grants are provided by other sources, but the amounts are relatively small. During 1967-68, the support to universities for research was as given in Table 1. This is for research in the physical sciences and engineering; the sources of communications research support are expected to be similar.

Table 1

Research Support to Universities in 1967-68

NRC	75%
Other government agencies	9.6%

Industry	3.4%
Private foundations	10.2%
University funds	1.7%

For purposes of this study the government university grants for research that is judged to be of communications interest have been divided into three categories; direct, long term, and very long term relevance (see appendix D for definitions). The level of communications research and development during 1968-69 is given in Table 11.

Table 11

Grants to Universities for Communications R&D, 1968-1969

Very long term relevance	$ .66 million
Long term relevance	$1.93
Direct relevance	$2.15
Total	$4.74 million

1.1.1.4 Summary

The total government funded research and development in communications in 1969 was:

Intramural	$ 7.5 million
Industry	$ 26.
University	$ 4.7
	$ 38.2 million

More detailed analyses of the distribution of these funds are given in appendices E and F of this study.

1.1.2 Industry - supported research and development in communications.

It has been difficult to obtain accurate figures for the amount of industry-supported R&D, partly

because problems of definitions and partly because of the difficulties in making a comprehensive survey. For this study figures were collected from two sources; from the R&D reported under the government aid programs of Industry Trade and Commerce (IT&C) and from a special survey carried out by the Electronics Industries Association of Canada (EIAC). Neither source is expected to give the complete picture, since some companies may not apply for government grants, and hence not be covered in the IT&C figures, and since the EIAC survery may not completely cover all the communications industry.

The level of R&D in the electrical & electronics industries supported by government programs in 1969 is summarized in Table 111, and is derived from the IT&C figures, (see appendix C) and from the addition of known government contracts ($4.0 million).

Table 111

Level of R&D in the Electrical & Electronics Industries		Financed by government support programs	
Commercial applications	55.5	Government aid	$16.8 million
Defence	20.6	IRDIA	5.2
Space and Communications	1.4		22.0
	$77.5	Government contracts	4.0
			$26.0 million
Government contracts	4.0		
TOTAL	$81.5 million		

The EIAC survey (see appendix G) indicated that the R&D expenditures in Canadian industry for the past three years were:

Year	Total expenditure
1967	$ 50.5 million
1968	$ 48.7 million
1969	$ 60.6 million

The two sets of figures do not agree, for the reasons stated above. However, one item is clear from both the IT&C and EIAC figures: about $49 Million were spent on telecommunications R&D supported directly by the telephone industry. The major portion of Canadian R&D in the communications sector is performed by business organizations that are corporately integrated and which have a manufacturing capability to support their service functions (see Appendix H).

Table 1V

Communications R&D in Canada

Government financed R&D

Intramural		$7.5 million
In-Industry		
Aid Programs	$16.8 million	
IRDIA	5.2	
contracts to industry	4.0	
	$26.0 million	26.0
Grants to Universities		4.7
	Total	$38.2 million
Industry financed R&D	approx.	$56.0
Total R&D effort		$94.2 million per annum

Total R&D carried out in industry

government financed	$26.0
industry financed	$56
TOTAL	$82.0 million

1.2 Areas of concentration of communications R&D in Canada

The areas of concentration are heavily weighted toward communications devices and systems, on the part of research done by industry and research funded in industry. In other words, as pointed out above, by far the most of the R&D done in industry, and over half of the total communication R&D done in Canada, is the development of systems or equipments for the telephone industry. This is largely a result of a decision within the telephone industry to retain control in Canada of the R&D done to meet their needs for advanced systems and plans, and to build up the required manufacturing capability in Canada. A 1967 EIAC study (appendix G) showed the areas of concentration, of a total R&D expenditure of $50.5 million, to be:

1.	Telephone and telegraph equipment and components	85.5%
2.	Radio Communication Equipment	10.0%
3.	Television and Radio Receivers	1.6%
4.	Electronic Computers and related equipment	1.3%
5.	Telecommunication Wire and Cable	1.0%
6.	Television and Radio Broadcast and Distribution Equipment	.6%

Both the radio communication equipment and telecommunication wire and cable categories include work directly related to research conducted in connection with the needs of the telephone industry; making this sector of the industry the predominate beneficiary of research activity.

Government and university R&D, which according to the figures gathered in this study accounts for roughly 1/6 of the total effort, tends to be primarily research rather than development. Intramural government research is primarily in communications, satellite technology, and research-supported spectrum management (see appendix A). University research tends to be primarily in the areas of: properties of semiconductors and solids, interaction of electromagnetic radiation with matter, properties of plasmas and the ionosphere, network design, information retrieval, and information-handling techniques using computers (see appendix D).

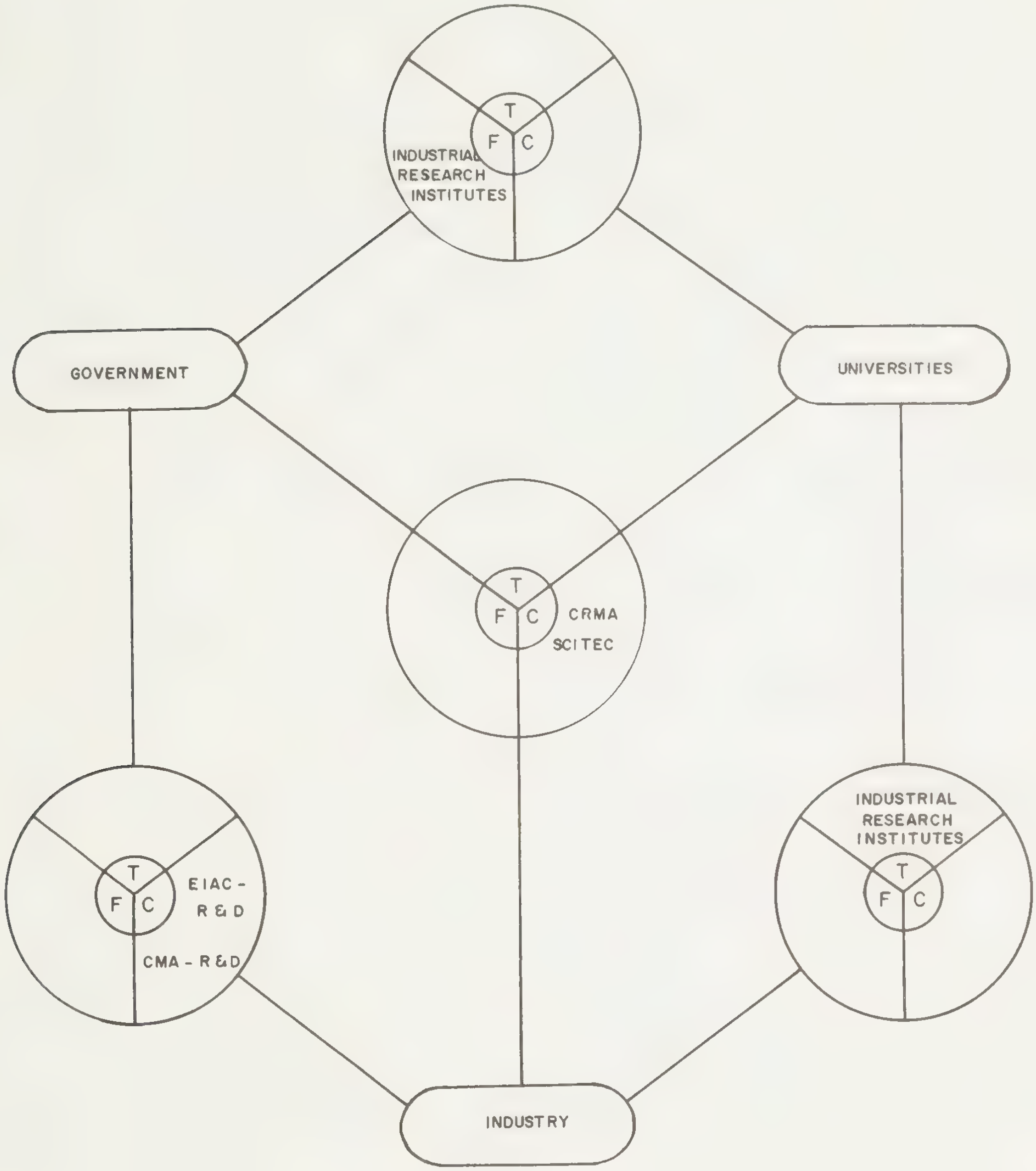
1.3 Coordination between government, industry and university research and development programs.

Coordination between government, industry and the universities in the R&D activities pertaining to communications takes many forms, and is the goal of several organizations.

The following schematic diagram is an attempt to summarize the relationships and interactions of the seven organization-types described in appendicies I to M.

1.3.1 Summary

The total R&D effort in Communications in Canada is summarized below in the diagram.



- DOMINANT FORMS OF INTERACTION

T - TECHNICAL

F - FINANCIAL

C - COMMUNICATING, INFORMATIVE

Chapter 2

Why Canada engages in telecommunications R&D

2. The electronics industry in general, and the telecommunications branch of it in particular, are keys to the survival and advancement of our society in the modern technological environment. Consider a single situation such as would develop if overnight the telecommunications used by the world airlines were to be rendered inoperative by any circumstance. Aircraft would be immediately reduced to the visual flying rules of the 1930s. Schedules would disintegrate. Business travel would return to the ground. We would be set back 30 years in time. An analogous situation would develop 20 years from now if all R&D in telecommunications ceased at this point in time. The following typical examples of reasons for continued Canadian R&D in telecommunications may be cited:

- to continue to enhance the strength of the economy through the strength of the telecommunications industry;

- to sustain an effective measure of independence from other economies in the event of a national or international crisis;

- to advance the effectiveness of Canadian industry at home and in world markets;

- to maintain centres of interest for the activities of our creative scientists and technologists.

2.1 Why the Government engages in telecommunications R&D

The role of the Government in communications R&D relates to both national needs and international commitments. R&D activities by the Government are based upon the need to maintain its body of scientific knowledge so that information is available upon which public policy and planning can be formulated. These activities may be classified as "In-House Research" and "External Research" and are designed to:

- introduce advanced technological skills into Canada;
- relate to the fulfilment of national objectives that cannot be reasonably undertaken in a commercial or university environment;

- augment the establishment of international science programmes in which Canada participates or supports;
- maintain sovereignty and freedom of action in international negotiations.

2.1.1 In-house research

The government must have the competence and ability to independently judge the relevance and implications to Canada of advances in the science and the technology of communications. Competence is secured through maintenance of research staff engaged in research programs as well as studies. Personnel are thus made available to interpret and evaluate current scientific and technological progress, to provide an interface with non-government experts and to produce forecasts. Principally, however, the research programs are mission oriented so as to advance knowledge in selected areas and on a predetermined scale.

Programs are initiated through a feed back process between management and research staff. Whereas senior management define the broad areas of interest, detailed project plans are initiated by senior levels of scientific staff. Specific proposals are judged against recognized requirements using the criteria of technical scope and scale, priorities, alternatives, suitability to available technical and staff resources.

2.1.2 External research

There are two types of programs

a) Those carried out under direct contract with the Government.
b) Those initiated under grants and development schemes.

Both classes of programs are designed to support the overall Government objectives. Additionally programs are favoured which will assist industry and the universities to staff and maintain centres of knowledge or expertise in communications technology or science (see appendix M).

2.2 Why industry in Canada engages in telecommunications R&D

Industry objectives are to produce and market goods and services with a favourable return on investment. Operations are normally conducted in a highly competitive environment, and companies must engage in research and development to maintain their products as to quality,

performance, and price, and to foster diversification and expansion into new product areas. Within the telephone industry services are provided in a regulated but monopoly market. Within this environment the industry's objectives also include the provision of service, taking into account interests wider than the economic conditions of the local market.

The product range of most technology-based industries consists of something between 50 and 80% of products which did not exist ten years ago. There is therefore a continuing need for replacement of technology. This can be done by importing new technology or by Canadian research and development. Both means are used in Canada. More applied research than basic research is conducted in Canada. To some extent basic research is a cultural activity which adds to our fundamental scientific knowledge, but cannot always be economically justified within Canadian industry. Because of its association with the generation of new scientific knowledge, research is often an activity best suited to the environments provided by universities and government laboratories where the production of goods and services is not the prime objective. Further, modern research tends to require expensive facilities beyond the power of a single company to support. Notwithstanding the difficulties, industry is now recognizing that some of the basic research necessary to ensure continuity of business must be done in industry where it can be product-/or mission-oriented. The amount of basic research conducted in Canada can thus be expected to increase (see appendices N and O).

To some extent research projects, but more often development projects, originate as a result of problems reflected from the production lines. By this means product improvements are made which incorporate the latest advances in technology. Research programs are undertaken before any radical product changes are made. Such research is usually related to the technologies in which the company is already expert. Products which require a radically different technology base are nowadays usually acquired by purchasing, either through license or another company rather than starting a new research program.

2.3 Why the universities engage in telecommunications R&D

The most obvious functions of the universities are teaching from the accumulated store of knowledge, and professional training. The universities also have always given leadership in adding to the store of knowledge. This is done by all forms of research conducted by the academic staff and the students. The best teachers from the

university point of view are those who are up to date in their subject and who maintain contact with the latest developments through research. Post-graduate training for students uses research studies to develop their reasoning faculty as well as their store of knowledge. An important motivation in university research, insofar as it rests with the staff and not the university organization, is the desire of the individual faculty member for advancement in his professional hierarchy. Research is one of the best ways for demonstrating an individual's excellence to his peers and especially to advance his reputation in the professional community at large.

Research conducted in the universities has the characteristic that it is done in a climate in which principally excellence counts, and there is no commitment to the solution of any particular problem and thus, no risk element in the economic sense. However, there is the concomitant characteristic that the university environment is not the most suitable for mounting large elaborate research programs, because the facilities used for research work are usually also used for teaching and training. (see appendix P).

Chapter 3

The initiation of research and development policies and programs

3.1 DOC Research and Development Program Review Procedures

Policy direction in the Department of Communications is concentrated at senior management level, but policy implementation and program-definition machinery is necessarily more diffused. The areas of research are determined as a matter of departmental policy. Within these research areas, there are inevitably a number of specific research projects that are immediately related to departmental objectives, and considerable flexibility normally exists in the assignment of research resources. This flexibility allows the Department to build up or cut back previously established research programs, and to maintain a research program in each area that reflects the changing achievements of the field of research, and any change in the priorities of the Department.

3.1.1 Management of Program

The management of a research program necessarily differs in many respects from the management of other operations. Because research is a creative activity which produces some form of innovation, the results often cannot be foreseen when the project is initiated, and it is often difficult to measure progress during the process of the research.

At present, the bulk of departmental R&D is done in the Communications Research Centre at Shirley Bay. The Director-General of CRC is responsible for the direction and management of the continuing research program. He is responsible for assessing the research program as a whole and its relation to external programs, and for making appropriate adjustments. This control involves a number of levels of line-responsibility within the laboratories. Information generated and exchanged between these levels usually has a powerful influence on the decision-making process in the direction and management of the research and development activity. Useful information for program assessment originates from many sources; from the results of the work already in progress; from the external environment, both national and international; from the explicit or implicit interest and competence of the scientific staff of the laboratory; and from the potential users of the scientific output.

The Director General of CRC reports to the Assistant Deputy Minister (Research) for the Department, who in turn coordinates the total departmental research activity with other departmental work. A Directorate for R&D is responsible for the policy implications of the research program and has the prime responsibility of coordinating departmental research activities with other government agencies.

The formal channel through which external inputs to program decisions are received is through the ARM(R), but in practice, much of this input arrives informally, at the working level, with the result that external information and advice on specific projects is more often directed to group and section leaders or directors of laboratories. This mechanism for acquiring planning information from outside is informal but real and valuable; its effectiveness depends critically upon the competence and accessibility of the laboratory staff.

3.1.2 Program Planning and Budgeting

The departmental program of which R&D is one activity is budgeted according to the Program Planning and Budgeting method used throughout the federal government for the past two years. PPB calls for continuing analysis at all levels of the resources required to achieve a particular objective. In other words, alternative ways of achieving the objectives are considered, and the plan that gives optimum results or outputs and benefits for a given cost is adopted. A five year forecast is an important feature of this concept.

PPB can assist in the management of basic research although it is generally accepted that the eventual output or benefit of research usually cannot be accurately quantified. As a case in point, the research leading to the invention of the laser has paid off in medicine by providing a new and versatile technique for welding detached retinas in the human eye; but the main goal of this research was and still is the attainment of amplification at optical wavelengths for a new generation of communications systems.

For research oriented to a specific application, i.e. applied research, and in experimental development, PPB can be helpful in the establishment of priorities and in determining the allocation of manpower and money. Although changes can be made during the life of a project, the main inputs by which competing projects are analyzed such as timeliness, chance for success, duration impact, and cost, can be estimated with a <u>useful</u> measure of confidence.

3.1.3 Program Review

Departmental programs are reviewed twice a year by both the Department and Treasury Board. The Program Review is submitted to the Treasury Board in May, and contains a summary account of the forecast for the next five fiscal years. The principle research activity is listed as "Communications and Space Application Research and Development". In October the Department submits its Main Estimates for the next fiscal year.

The Program Review prepared in the spring and the main Estimates which are considered each fall are the culmination of the program formation process; they reflect a formal judgment of the programs calculated to secure the objectives of departmental policy, and are regarded as the definitive statement of the research plan.

3.2 The initiation of R&D in industry programs

3.2.1 The role of systems engineering in the communications sector

The telecommunications carrier network is a complex entity continually undergoing change and evolution. Systems engineering is a vital function in the R&D process, with the task of optimizing the economic and technical design of the overall network, taking into account both initial capital requirements and ongoing operating and maintenance expenses. This involves the introduction of changes in the form of new products, or new designs of existing products, which must be suitable for and integrated into the network. The public telecommunications network is like a living organism. While it is constantly changing, it is important that all new equipment be compatible with the existing network which represents an investment of many billions of dollars. Systems engineering, from a slightly different viewpoint, has the task of deciding what should and can be done, optimizing the use of resources for this purpose. As a bridge between the user and the developer, the systems engineer must interpret the user's requirements to the developer, and interpret the state of the art and development capabilities to the user (see appendix Q).

3.2.2 Economics of research and development

Two important aspects of the economics of R&D for a manufacturer are: the costs of R&D in terms of total costs of sales, and the benefits that can be anticipated.

The costs of R&D as a function of total start-up costs are heavily influenced by the nature of the production process. For those products which are amenable to the production-line approach, a significant part of the start-up cost may be in tooling and manufacturing set-up. This can cause R&D costs, i.e. those costs up to and including the costs of producing manufacturing drawings, to be as little as 15% of the total costs of producing a marketable product. Because such products are in general directed to a diverse market, sales are likely to be large, so that R&D costs can be as little as 1%,of potential sales.

Products fabricated on a job-shop basis, on the other hand, are usually directed towards less diverse markets and have more limited sales. Because of this, and because their production set-ups are less capital-intensive, R&D costs might be as high as 50% of start-up and 8% of sales. Total start-up costs will run as high as 20% of potential sales for products of this nature.

Although many of the factors influencing decisions on the ultimate profitability of new product development can be only roughly estimated, techniques of calculating for decisions are being increasingly used. These make use of estimated innovation costs and time, production costs, sales volume and commercial life, and use a discounted-cash-flow calculation. This generally produces a return-on-investment ratio, which is then one of the factors used in deciding whether or not to proceed with the development.

3.2.3. How companies carry out R & D programs in Canada

Procedures governing industrial R & D programs tend to vary with company size and ownership. In large companies, the flow of ideas, plans and proposals is generally upward through the organization, whereas in small companies it is usually downward from the senior officers. This may be so regardless of the ultimate origin of the ideas for new products, which can be from many sources, including customers and marketing departments. In any program, large or small an idea must evolve into a program plan to consider technical, economic and human factors collectively The risks of success or failure must be estimated, and the profitability of the venture assessed. It must represent a reasonable use of available resources.

Financial approval is handled in varying ways. In large companies with an R & D establishment, there will usually be an overall R & D budget approved on an annual basis by the President and board of directors. Within this budget, each major project will be given separate approval at various levels. Smaller companies may require corporate approval for all projects.

The development process itself may begin with an exploratory phase, in which more than one approach to the final design may be tested for its ability to meet the technical and economic requirements. Close interaction is necessary in this period between the development team and the systems engineers or their equivalents. The exploratory phase may be considered complete upon the demonstration of technical and economic feasibility, when a working prototype meets design requirements and when satisfactory costs are predicted for the design based on this prototype.

"Hard development" begins at this point, and is characterized by tight goals in time and expenditures, with product characteristics firmly specified. There must be sufficient flexibility to permit changes offering cost reduction. There should be close involvement, at this stage, of those responsible for the design of tools, test fixtures and production facilities, and of marketing and installation people as well, so that the design is more likely to meet its targets of manufacturing cost and salability.

Development may be considered complete after successful field trials of a sample product made from standardized drawings by the production methods to be used in full-scale manufacture. To reach this stage requires the successful completion not only of the engineering design but also of the tooling and manufacturing set-up. These are all parts of the innovation process, as is marketing, and they must be done successfully in a sufficient number of cases if the company is to stay in business. While basic R & D, either in-house or purchased, is essential to new-product development, it is only one factor. It must be supplemented by the processes of design and tooling, and the provision of adequate manufacturing facilities and marketing capability in order to successfully bring products into use (see Appendices R & T). A schematic explanation of the industry decision process is contained in Table V.

Table V

How Companies carry out R and D programs

	Large		Small	
	Canadian Owned	Foreign Owned	Canadian Owned	Foreign Owned
1. Origin of Ideas	Engrg or Scientific Marketing Middle Mgmt Customer Owner Individual	Parent Engrg or Scientific Marketing Middle Mgmt Customer Individual	Senior Mgmt Single individual customer	Parent to subsidiary or - individual or customer to subsidiary to parent
2. Program Plan Corporate	President & Planning Staff	Corp HQ	President	Corp HQ
Technical	Canadian Engrg & Scientific Staff	Cndn or Foreign Engrg & Scientific Staff	Own Engineering Staff	Corp Engrg Staff
Marketing	Marketing Staff	Canadian & Corp International Staff	Own Marketing Mgr	Canadian Marketing Mgr
Manufacturing	Manufacturing Staff	Cndn Mftg Staff	Production Foreman	Parent technology set-up
Financial	Comptroller	Corp HQ & Cndn Comptroller	President	Corp Comptroller
3. Program Approval	President, Comptroller & V/Presidents	Corp HQ	President	Corp HQ
4. Funding Source	Own Responsibility	From Cndn Resources and/or Corp Resources	President (responsibility)	Corp HQ
5. Program Execution R & D & Mftg data transfer	Engrg & Scientific Staff	Cndn and/or Foreign Staff	Chief Engineer	Nil
Technical Data (Imports) transfer	"	"	"	Production Foreman

	Large		Small	
	Canadian Owned	Foreign Owned	Canadian Owned	Foreign Owned
5. cont'd Modification Program	Engrg & Design Staff	Cndn Engrg & Design Staff	"	Nil
Mftg Program	Mftg Staff	Canadian Mftg Staff	Production Foreman & Purchasing Agent	Production Foreman & Purchasing Agent
Marketing Development Program	Marketing Staff	Canadian Marketing Staff	President & Marketing Mgr	Manager & Sales Staff
Sales/Shipments	Marketing Staff Mftg Staff	Canadian Marketing Canadian Mftg and/or Corporate Mftg	President, Marketing Mgr Production Foreman	Manager & Sales Staff Production Foreman
Customer Feedback	Marketing	Canadian Marketing	Top Management	Manager & Sales Mgr
Plan Modification	Marketing, Engrg & Scientific Staff Manufacturing Top Management	Canadian Marketing, Engrg & Scientific Staff Cndn Mftg Cndn Management Corp HQ	Top Management	Corp HQ

3.3 The initiation of R & D programs in universities

It is convenient to divide research programs in universities into two catagories: (a) small and (b) large.

3.3.1. Small programs.

The characteristic feature of small programs is that they are the personal research of an individual university staff member. There may be collaboration with other staff members, but this is unusual. An individual will choose such a program because it excites his curiosity or will advance his reputation within the university. His next step is to find money to finance it. Sometimes special facilities are needed and these may already exist in the university (which would be an incentive to choose that particular program), or they may have to be sought or bought.

The usual source of funds is the National Research Council, and the staff member makes application to NRC in December. His application is reviewed by a "grant screening committee" and funds are granted for a period of one year from 1 April to 31 March. The most important factor in the choice of a "small research project" is the intellectual curiosity of an individual; the principal criterion used by the N R C grant screening committee is its scientific value. The amount of the award is rarely more than $10-15,000 and is not large enough to build an establishment or to pay much in the way of salaries.

3.3.2 Large programs.

Large research programs may require up to $1 million or more. They involve a research team, or collaboration between several staff members, and depend on a commitment by the university and the granting agency to continuity for several years.

These programs are usually proposed by individual staff members (or by groups of staff members) prompted also by intellectual curiosity, but a pre-requisite is some indication that such an effort has a chance of sucess. The negotiated development-grants program of the N R C is an example.

Contracts with industry are another source of funds for large-scale research programs in universities. It is difficult to establish any pattern but again the initiative often comes from the university staff member. Some universities have fostered the appearance of organizations that actively seek industry funded research projects to be carried out by university staff using the universities labratory facilities.

Chapter 4

The effectiveness of present research and development policies and programs.

4.1 The need for establishing specific goals and objectives

The previous chapters have described a variety of activies which together constitute the total R & D effort related to communications in Canada. While not organically coordinated, this total activity constitutes an existing system. To measure its effectiveness one must either know or assume criteria against which effectiveness can be assessed, a method of measuring existing performance, and means of estimating whether the output of the system is the result of existing mechanisms or some other contributing factor.

For criteria against which one can measure effectiveness, a baseline can be established by assuming a set of overall goals for research and development activities in the communications sector. For the purpose of this study and the exercise of measuring the effectiveness of R & D policies and programs, the following goals are assumed. They are not introduced as definitive, or even suggested as being complete, except for the purpose of this study. R & D capabilities must be on a scale:

- to maintain national communications systems and networks;

- to maintain Canadian industry at a competitive level, both domestically and internationally;

- to develop a pool of skilled manpower able to comprehend and analyze the effects of scientific advances in communications and their impact on national, political, social and economical goals;

- to enhance the ability to predict future communications-technology advances and problems

Measured against these broad goals, R & D activity in industry, universities, and government in past years has contributed positively and has been relatively effective. In the communications sector, Canada is among the world's technologically advanced nations. Proportionately to other advanced nations such as the United States, Canada can call on a large number of highly trained, imaginative, and competent researchers.

To establish more specific criteria of effectiveness is difficult, not only because of the subjective judgments that must be made on the capacity of individuals or groups, but also because the large amount of activity in a system that is not tightly coordinated or inter-related. But some general observations on the effectiveness of present activity can be made. First, there is a recognition that any organized R & D activity produces results which tend to maintain the system; this is applicable not only to the development of large program objectives in government laboratories but equally to isolated research activities in universities, or to the R & D of industrial groups. An example of the self-feeding effect is the N R C university grant program, which usually favours small grants to individual researchers for individual projects. This program has tended to concentrate university research activity in isolated research effort; for this purpose, the system is most effective, although whether this was the intention of the program, or whether it is a desirable end, has not been examined.

In larger and more integrated R & D activities there is the recurring difficulty of trying to determine when the program is no longer effective and should be terminated. The tendency for R & D to be self perpetuating is real. Managemnet of R & D is still as much an art as it is a science. In chapter 3, the way in which R & D activities are initiated in various environments was outlined. There is no doubt that in recent years the determination and selection of research projects by measurement against specific objectives, so as to increase their effectiveness, has increased. However, the goals and objectives of one research group often do not relate to the goals and objectives of other groups, and in many cases R & D activities in communications in Canada do not relate to the objectives established in this study as a possible baseline for measuring national activity.

To meet national goals a minimum level of activity must be maintained. Within the industrial sector there seems to be little agreement between companies as to the level of R & D activity needed to maintain competitive capability. While there has been some investigation in the past, which has been rather disheartening in its result, there seems to be an argument for further research to determine whether the relationship between R & D activity and technological capability in the communications industry can be effectively judged.

4.2 Desirability of establishing a measurement to establish priorities between objectives

The establishment of goals and objectives does not ensure that R&D programs become effective. There will have to be strategies devised for achieving agreed upon goals, and one of

the first problems in organizing those strategies is the determination of a measurement that will establish a ranking or priority listing between several objectives. This will be a difficult task and will be accomplished only by a recognition that any ranking of objectives can be accomplished by accepting both objective quantitative analysis and subjective value judgments. For example, while at the present time there is increasing support for shifting emphasis in R&D from basic research to applied research (the phrase 'mission-oriented' is used as a synonymous term), the accomplishment of that goal should be assessed not individually but in the context of total research aims. If 'mission-oriented' is interpreted as meaning that all research should be fitted into a specific overall plan with fixed objectives, the result would be detrimental to long-term national needs. Over-emphasis on applied research programs could channel activities into too few lines and leave Canada dependent on foreign sources for science and in technologies not foreseen when objectives were established. R&D effort is not a prestige activity;it should be related to economic and social ends but, in the creation of policies to support R&D, there is a constant risk of being limited to the enunciation of generalities, or at times mere slogans, which do not in the end aid in the determination of programs or activities that bear any relationship to national needs.

The increasing complexity of R&D activity and R&D management suggests that, for a true determination of priorities between objectives, there will have to be a closer degree of association between universities, government, and industry, with a clear understanding and, more importantly, agreement on the means to attain objectives. Development of strategies, as well as development of goals and priorities, will probably entail not only a sharing of knowledge between different sectors of research activity but also a sharing of risk. It will also call for better utilization of available manpower and, not least, the development of administrative machinery to review strategies and goals periodically, so that resources can be shifted and priorities reconsidered for maximun benefit.

4.3 Extent of coordination

With the exception of the telephone industry, and particularly the Bell-Northern electric complex, any large-scale coordination of Canadian R&D has been more fortuitous than planned. In the former case R&D activity has been built into an industrial structure that provides products and services on a national scale. This coordination has been achieved by integrating the planning, engineering and manufacturing stages with R&D activity and has in the opinion of the companies been facilitated by the vertically integrated corporate structure of the companies. In other

sectors, what coordination of activity has taken place has been attributable partly to the relatively small size of the community of researchers, which eased the problem of exchanging information.

In some ways the NRC grants committees have acted as coordinating bodies, particularly with respect to university research. The government support programs to industry have also had salutary effects as an information clearing-house. However, as the level of activity has increased, as new laboratories opened, and as the body of knowledge to be explored widened, *ad hoc* arrangements have become fragile, and the relationship of research activity to national goals is becoming more accidental than planned.

Chapter 5

Communications R&D policies and plans for the 70's

If the industrial revolution was essentially an extension of man's muscular capabilities, then the technological revolution is really an extension of his intellectual capabilities and more specifically, his ability to organize, manipulate and use large amounts of information.* This technological revolution has led us directly into a further, and more fundamentally important change which can be called the "communications revolution". In terms of techniques and facilities, this latter is just a part of the technological revolution but in terms of the effect upon our society, the availability of modern facilities for near instantaneous transfer of large volumes of information directly between individuals and to mass audiences it is also producing a social revolution of major proportions. To give but one example, the communications revolution has given an individual the ability to view, in nearly real time, events and conditions in any part of the world. It has also given people throughout our society the ability to organize and participate in particular social or political functions, in a way that was not even remotely possible before the advent of the telephone and television. The ability of the society to react quickly and en masse to a particular stimulus has introduced new dimensions into our civilization, and we have only begun to experience the changes that this communications revolution is likely to bring.

By the very nature of its involvement with the rapidly advancing field of electronics, communications is intimately involved in advanced technology, and with the research and development that leads up to the introduction of advanced systems. At present, the relationship between research and the implementation of advanced communications systems is evident. What is less clear is whether a manufacturer of telecommunication products or a supplier of services must, to remain competitive, have his own research capability or at least access to a research base that relates to determined needs. This is a point clearly made by the telecommunications industry, particularly the common carriers, to the extent that they argue that the research and development functions must be vertically integrated with the operating and manufacturing functions.

*Reference (J.J. Servan-Schreiber) "The American Challenge" - Athenerm - 1968.

This intimate relationship between R&D and the implementation and operation of systems has an important effect upon R&D policies. Considering that at least half of the present R&D activity is closely associated with the operating companies, it follows that it is very closely geared to the needs of existing communications systems, and to the expected needs of the future, as predicated by the operating companies themselves. The other half of R&D activity is less specifically directed. However, the effect upon R&D policies and activities of the presence of an existing vast and expensive communications system can hardly be overestimated. It means that any R&D that is done by industry on advanced systems and techniques is inevitably constrained by the existing system, and by the fact that many elements of that system were installed many years previously.

The study team agreed that R&D in the communications sector is of direct and primary relevance to the establishment of advanced communications systems in Canada. Since the facilities that these systems provide are creating a communications revolution of very real proportions, R&D policies and plans in this area are of paramount importance to the country. The factors that govern the R&D policies and plans, and the effect that the existing policies and plans may have on our society, through the impact of the resulting technically advanced communications are difficult to determine or analyze. In Canada most of the R&D policies have evolved out of the particular goals of the unit or sector in which the research is done, usually more or less divorced from other units or sectors, seldom in a national context. This has unduly complicated a rational examination of R&D at the policy level. Certainly none of the sectors have so far tried to relate their R&D activities to a serious consideration of the sociological effects of communications systems that may be based on the results of R&D. This is a factor that can no longer be ignored and new methods of policy formation, both with respect to methodology and quantitative analysis techniques are needed. Much of this work will have to be focussed on future requirements, forecasting possible future technologies and the needs and emerging living patterns of society. This factor is so important that we must begin, by trial and error if necessary, to develop the required techniques for taking these effects into account in R&D policy formation. (See appendicies U & V).

The project team also considered that the time has come to establish a set of communications goals, defined in a national context, from which the various sectors of the communications community can operate, and against which industrial, academic and government R&D policies and programs

can be established. These goals could be general, rather than specific. The need is that they be articulated and made known so that they can be discussed and debated. Once a set of goals has been enunciated, techniques of planning exist for optimizing the progress toward meeting those goals.

The project team realized that, at present, each of the three sectors, university, industry and government, play particular and rather separate roles in communications R&D. However, it is evident that the present attitudes and approaches in all three sectors must change, and become more flexible if we are to achieve our goals, better utilize our manpower and financial resources, and improve the effectiveness of our policies and plans. All three sectors must accept reponsibility for accomplishing all national goals. It seems hardly satisfactory for one sector to assume that it does not have a responsibility to ensure that its R&D policies and programmes contibute to and take into account all of the communications goals. In the end this may lead to different types of research being undertaken at various sector of activity. This type of integrated approach would mean a continuing reexamination of the degree and form of public funding of good directed R&D activity. To be effective there must be a continuing interaction between the industrial, government and university research communities so that goals and objectives are understood and pursued. To this extent more formal mechanisms of liaison and cooperation appear warranted. At present some sectors of the manufacturing industry cannot sustain adequate R&D programs even though they have demonstrated an ability to make a contribution to the national R&D effort.

R&D policies must flow out of long term planning that clearly measures future requirements and which considers the impacts of future technologies. The communications revolution is a mental or intellectual revolution -- a revolution in the exchange of ideas and information -- and we can optimize our chances of shaping it to desirable ends only as we work from a base of both technological and social knowledge. It does not seem possible to stop technological development. The most that can be done is to either slow it down, or perhaps divert it from one channel to another. Communications is an area in which we must have a high level of research activity, higher than we have now achieved, if we expect to be able to benefit from the technology in a knowing manner. We need the advanced and improved systems of communications that our R&D can evolve. They can enrich our lives and our culture in valid and exciting ways. Advanced communications systems can give the individual an exciting and satisfying sense of participation in events and projects of real significance. But at this stage we are far from knowledgeable in the consequences of piece-meal implementation of such systems, or of the other changes that need to be made to our society to allow

it to cope with interim systems, and to adjust to the new dimensions that we can clearly see are available.

Appendix A

Communications Research and Development At CRC, 1969-70

The in-house budget of CRC is about $7.5M. In addition during the current fiscal year about $4M has been approved for industrial contracts managed by CRC.

1. Communications Research — 33% of Total Effort

1.1 Cable, Radio and Optical Communication Techniques

Research on the efficient and economical use of communication channels includes applications relevant to current systems (microwave, troposcatter, narrowband cables and wire channels) and basic work on future systems (wideband satellite cable channels, optical systems). Digital techniques and digital switched systems are emphasized, because of their importance to future communication systems (such as the "Wired City").

1.2 Satellite Communication Techniques and Systems

Research on satellite communication techniques and systems for future domestic civilian requirements, including problems relating to communications with small ground terminals, aeronautical communications and navigation, and direct broadcast systems.

1.3 Northern Communication Techniques

Research on communication problems peculiar to the Canadian North over the entire frequency spectrum; including VLF, LF, Broadcast, Short-Wave, VHF scatter, UHF radio relay, microwave communication satellite, and optical laser systems. A present emphasis is the evaluation of northern communication requirements in the light of new technology, with particular reference to the second generation TELESAT.

1.4 Computer and Information Systems.

CRC staff designed, built and used the first Canadian solid state computer. Digital computer systems form an integral part of many CRC research projects. The CRC now uses a SIGMA 7 computer.

Applications of coherent optical systems (holography) for data processing and storage are being developed. Digital computers are being applied to sophisticated signal-processing with specific reference to data collected by direction-finding arrays.

1.5 Radar Techniques and Systems

The current program on radar techniques and systems is presently connected with military systems, with emphasis on problems connected with remote sensing of military targets.

2. (a) Satellite Technology 32% of Total Effort

2.1 Space Mechanics

The design of spacecraft structures for the Alouette/ISIS program, TELESAT, and proposed future Canadian satellites includes: large antenna systems, extendible booms, flexible extendible solar-cell arrays, attitude control systems, and space propulsion systems. Related theoretical work includes the thermal design of satellites, and the analysis of station-keeping and of the dynamic behaviour of flexible satellites.

2.2 Space Electronics

Research on electronic systems in spacecraft - such as command, control, programming, telemetry, power-supplies, on-board computers and data-storage, sensors, probes, etc. Studies are under way for future satellites.

2.3 Reliability Analysis

Spacecraft systems must be at least one order of magnitude more reliable than conventional electronics. Intensive examination of individual components and integrated circuits is essential at all stages of the development and engineering of a spacecraft. CRC has recently established a scanning electron-microscope facility, and associated research devices, for examining the detailed behaviour and physical properties of microelectronic and integrated circuits under their anticipated operating conditions.

2.4 Integrated Circuits

Integrated solid-state circuits offer the advantages of small size, reliability, and low power consumption of spacecraft electronics. An experimental facility has just been established at CRC for made-to-order integrated circuit components.

2.5 Satellite Development

Research on problems in space electronics and mechanics which arise from current industrial development contracts, and operation of the industrial-contract management office.

The first operational use in Canada of the project evaluation and review technique PERT was made on Alouette II, and PERT has since been imposed on the contractors for ISIS-I and ISIS-B. A multiple-incentive type of contract was arranged for ISIS-B, and indications are that this will result in substantial savings. This topic covers the work performed by CRC for TELESAT Canada.

2.6 Satellite Operations

Alouette I, Alouette II, and ISIS-I are operated under CRC control. The Satellite Controller's Office schedules satellite operations throughout the world. Ground telemetry receiving stations are installed at Ottawa and Resolute Bay, and the CRC Data Processing Centre reduces the telemetered data to a format suitable for scientific analysis and for use by World Data Centres. The Prince Albert Radar Laboratory is being examined as a potential receiving station for earth resource satellites.

2. (b) Spacecraft Development Contracts 20% of Total Effort

The Alouette II and ISIS-I satellites were built and ISIS-B is now under construction in Canadian Industry.

3. Research Supporting Radio Spectrum Management 15% of Total Effort

3.1 VHF, UHF, Microwave and Optical Radio Propagation

CRC is the Canadian national centre for propagation research across the entire radio

spectrum, including the laser region. The research program concentrates on propagation problems peculiar to Canadian latitudes, with a view to applying the results to current and future domestic communication systems. In the VHF, UHF, and microwave part of the spectrum the main interest is in the limitations of the trasmission medium, particularly the lower atmosphere, and the effect of such limitations on the allocation and sharing of the radio frequency spectrum.

3.2 VLF, LF,Broadcast and Short Wave Radio Propagation

Propagation research at the lower radio frequencies, the short-wave band and below, is particularly concerned with applications to radio predictions and forecasting for domestic communication systems. The most critical propagation problems here are associated with the properties and behaviour of the ionospheric and, accordingly, the program includes basic research on the disturbed Canadian ionosphere.

The VLF and topside-sounder experiments in the Alouette/ISIS satellites form part of this program.

3.3 Radio Noise and Interference

Research on radio noise sources and the observation and interpretation of noise and interference, in relation to practical communication systems.

3.4 Radio Prediction and Forecasting

CRC provides a radio prediction service to domestic users of long-distance LF, HF, and short-wave communication systems. These systems are affected by ionospheric variations, and their operational efficiency can often be greatly improved through the use of the prediction service. CRC also provides computer programs to users who wish to prepare their own predictions on a routine basis. The program includes research on improved methods of prediction, and on the development of techniques for short-term forecasting of communication circuit conditions.

Source: Department of Communications.

Appendix B

Government Programs supporting R&D in Communications

The largest support program is the Defence Industry Productivity Program (DIP) approved in 1968. The immediate objective of DIP is to develop and sustain the technological capability of Canadian industry for the purpose of defence export sales or civil export sales arising from that capability through a variable cost-sharing between the department and the industry for selected projects. Up to 1968 DIP commitments in the telecommunication field amount to $29.5 million.

The Program for the Advancement of Industrial Technology (PAIT)

The Program for the Advancement of Industrial Technology was initiated in 1965, to help industry help itself to improve its technological capacity and to expand its innovation activity by underwriting development projects which involve a genuine technical advance and which, if successful, offer good prospects for commercial exploitation. If the project is successful, the contributions are written off. However, PAIT has been recently expanded and financial support can take the form of a grant. The costs of the project are normally shared between the government and industry. Up to 1968, PAIT expenditures in the telecommunication industry amounted to $346,000.

The Defence Industrial Research Program (DIR)

The Defence Industrial Research Program administered by the Defence Research Board began in 1961 and was designed to improve the ability of Canadian companies to compete for research, development and production contracts in the United States and NATO defence markets. Preference is given to long-term projects which offer good potential for achieving major advances in performance and techniques. Up to 1968 program expenditures amounted to $7.4 million in telecommunications.

The Industrial Research Assistance Programs (IRAP)

The Industrial Research Assistance Program was initiated early in 1962 to create new research facilities within the industry and to expand existing facilities, to improve communications between research workers in government and industrial laboratories. The government through NRC pays direct salaries of approved research programs undertaken by

industry for five years. Up to 1968, expenditures under IRAP totalled $569,000 in telecommunications.

The Industrial Research and Development Incentives Act (IRDIA)

The three year old Industrial Research and Development Incentives Act (IRDIA) provides general incentives to industry for the expansion of scientific research and development, and is administered by the Department of Industry, Trade and Commerce. The program provides applicants with tax-exempt grants for increased R&D, and equals 25% of the aggregate of a company's R&D capital expenditures and of the increase in the current R&D expenditures during the fiscal period over the average of the preceding five fiscal years. In 1967, grants totalling $5.2 million were provided for the telecommunication industry.

Source: Department of Industry, Trade and Commerce.

Appendix C

The R&D Industry - Quantitative Analysis by Dept. of IT&C

R&D expenditures in Electrical & Electronics Industry

Total intramural R&D expenditures by industry in 1967 were $94.7 million of which $11.5 million were capital expenditures on R&D facilities. Of the current R&D expenditures, $5.6 million were spent in the field of nuclear energy, $1.4 million on space and communications, $20.6 million on defence and $55.5 million on commercial applications. For 1968, these expenditures were projected to be $93.7 million and $7.8 million respectively.

Of these 1967 expenditures, $16.8 million were funded by the Canadian Government and $1.5 million were funded by foreign governments. These government-funded sums do not include grants received under Industrial Research and Development Incentives ACT (IRDIA), under which industry claimed $10.2 million in 1967.

In 1967, the total R&D expenditures in communications electronics (i.e. telecommunications, detection and navigation, computers and instrumentation and parts) if based on IRDIA claims, were $74.2 million. Out of this $49.860 million were claimed to be in the telecommunications field and were therefore eligible for grants amounting to $5.2 million. Seventeen companies were involved in IRDIA grants in the telecommunication field as against 62 for the whole electronics industry.

Government support for R&D in telecommunications

Federal Government expenditures on R&D for the years 1968-69 amounted to $11 million for work in the communication field undertaken by DRB, NRC and CRC. However, the Department of Industry, Trade and Commerce finances R&D by sponsoring special assistance programs designed to increase R&D capability of Canadian industry. At present, there are five continuing programs of government support in operation.

Source: Department of Industry, Trade and Commerce.

Appendix D

Level of R & D Activity in the Communications Sector in Canadian Universities

For the purpose of this section grants have been divided into three categories:

(1) Direct relevance. Research projects with direct relevance are those which attack some specific problems in telecommunications.

(2) Long-term relevance. Research projects in this category are directed towards the extension of knowledge in a field known to have some relevance to communications at the time it was initiated (an example would be studies of impurity states in semiconductors). Although the person proposing the project may be interested only in certain fundamental solid-state physics problems, he is well aware that its results could have an immediate bearing on transistor technology.

(3) Very-long-term relevance. In this category are research projects which have no obvious connection to telecommunications at the time of their inception. Yet they are in fields where some application in telecommunications may well be found. Almost any project involving the interaction of matter with radio-frequency radiation might come under this category.

It should also not be forgotten that long-term and very-long-term projects may have some relevance to telecommunications but direct relevance to other problems; therefore when the support given to these projects is computed it should be recognized that there may be an overlap with the computation of support given in other fields.

The areas of concentration of research in communications comprise:-

Properties of semiconductors and solids
Interaction of electromagnetic radiation with matter
Properties of plasmas and the ionosphere
Network design
Information retrieval and information handling techniques using computers.

The pattern of R and D in the universities has remained constant for several years. About 75% of the support comes from

NRC, and the other 25% from other agencies; in communications these are D.R.B. and A.E.C.B. The total level of support is about

$2.2 million on projects of direct relevance
$1.9 million on projects of long-term relevance
$0.7 million on projects of very-long-term relevance.

The total for all projects relevant to communications is $4.8 million.

The sum spent on salaries is about $1.6 million, made up of

- $214 thousand for graduate student support, (at present about 5.6% of the NRC total).
- $955 thousand for technical salaries (about 20% of the small or personal grants and 50% of the large or block grants).
- $455 thousand for professional salaries (Ph.D. or higher).

The rest is spent on equipment, supplies, and operating expenses.

Geographically, this support is distributed in the following way:-

Maritimes	$156,000
Quebec	$881,000
Ontario	$1,725,000
Prairies	$1,381,000
British Columbia	$546,000

The support on all aspects (including very long term) of communications research in the Universities comprises about 5.3% of total University support. It can be reasonably estimated that this involves a total of 260 scientists and engineers. Technical and support staff would be in addition to this number.

The following figures, indicating the pattern of research support in the universities in general, are taken from the MacDonald Report.*

Table I

Support to Universities in 1967-68

	(in million$)	
N.R.C.	66.3	75 %
Other government agencies	8.6	9.6%
Industry	3.0	3.4%
Private Foundations	9.0	10.2%
University funds	1.5	1.7%
Graduate Student support:-		
(a) from N.R.C. grants	3.8	5.6% of the N.R.C. support
(b) from N.R.C. scholarships	4.1	

Although the total may change from year to year, this pattern is approximately constant.

From a list of grant titles supplied by NRC and DRB the support for research and telecommunications through those bodies and the Atomic Energy Control Board has been listed in Table II.

Table II*

N.R.C. Categories	Very Long Term	Long Term	Direct
Physics & Nuclear Physics	$217,752	$ 181,525	$ -
Space & Astronomy	162,119	166,490	631,470
Electrical Eng.		841,896	848,817
Mechanical Eng.		38,590	89,620
Mathematics		58,490	13,590
Computing		159,440	34,044
N.R.C. Negotiated Major Grant		125,000	254,980
A.E.C.B.	227,550		
D.R.B.	48,200	358,094	276,764
Totals	$655,621	$1,929,525	$2,149,285
Grand Total $4,734,431			

*The Role of the Canadian Government in Support of Research in Canadian Universities, Special Study #7 The Science Council of Canada & The Canada Council 1969.

Out of the total support of \$4.73 million, NRC. supplies 73% in small grants, 8% in large grants, a total of 81%. The DRB contribution is 14.5%, and the AECB contribution 5%. This breakdown is very similar to that shown in Table I.

Table III gives an estimate of the amount spent on salaries. Very little of this money goes towards professional salaries in universities, but a substantial amount goes towards technical salaries and graduate-student support. It is difficult to get an accurate estimate of this breakdown without access to the auditor's reports of the grantee institutions. However, it is fairly easy to estimate the level of support for graduate students as 5.6% of the N.R.C. total on the assumption that it follows the established pattern for all NRC grants. It is probably correct to estimate technical salaries as being approximately 20% of the small grants and 50% of the large grants (N.R.C., D.R.B., and A.E.C.B.). The results of this computation are shown in Table III.

Table III

Estimated amount shown on salaries

Graduate students	5.6% of N.R.C. Total	\$ 214,000
Technical salaries (i)	20% of small grants	765,000
Technical salaries (ii)	50% of large grants	189,990
Salaries	50% of D.R.B. and A.E.C.B. grants	455,304
		\$1,624,294

Source: Dr J.M. Daniels, University of Toronto

Appendix E

NRC and DRB University Grants, 1968-69

Research Relevant to Communications

University	NRC Long-Term Relevance Funds	Direct Relevance Funds	Total	DRB Funds	Grand Total
Acadia		3,430	3,430		3,430
Alta.	124,345	87,740	212,085	8,500	220,585
Bishops	1,600		1,600		1,600
U.B.C.	327,248	93,130	420,378	43,511	463,889
Calgary	201,340	250,184	451,524	8,000	459,524
Carleton	13,720	38,780	52,500	16,200	68,700
C.M.R.				11,700	11,700
Dalhousie	3,480	5,390	8,870		8,870
Lakehd.	10,310	7,350	17,660		17,660
Laurentian	10,190	13,050	23,240		23,240
Laval	77,910	117,960	195,870	52,994	248,864
Lethbridge	3,920		3,920		3,920
Loyola	4,249		4,249		4,249
Manitoba	49,880	71,790	121,670	18,700	140,370
McGill	114,710	126,712	241,422	28,800	270,222
McMaster	94,670	57,865	152,535	32,600	185,135
Moncton	3,430		3,430	20,000	23,430
Montreal	145,320	16,860	162,180		162,180
Mem. U. Nfld.	14,450		14,450		14,450
New Br.	33,120	34,650	67,770	12,900	80,670
N.S.T.C.	36,750	17,640	54,390		54,390
Ottawa	32,340	22,050	54,390	11,800	66,190
Polytech.	12,250		12,250		12,250
Prince of Wales		3,430	3,430		3,430
Queens	50,260	39,730	89,990	9,000	98,990
RMC				31,353	31,353
Sask.	247,450	326,660	574,110	32,300	606,410
Sherbrooke	29,570	12,720	42,290	6,500	48,790
Simon Fraser	16,390	30,100	46,490	42,600	89,090
Sir Geo. Wms.		7,350	7,350		7,350
St. F. X.	1,1960	1,960	13,920		13,920
Toronto	209,140	332,340	541,480	86,900	628,380
Trent				7,000	7,000
Victoria		4,000	4,000		4,000
Waterloo	91,206	155,390	246,596	26,200	272,796
Windsor	21,870	38,910	60,780	10,600	71,380
W. Ont.	57,010	161,785	218,795	52,000	270,795
York	16,170	14,000	30,170	6,000	36,170
TOTAL	$2,066,258	2,092,956	4,159,214	576,158	4,735,372

Appendix F

NRC Grant to Universities 1968-69

Research Relevant to Communications
by Activity

I. Physics and Nuclear Physics

	A. Long Term Relevance	B. Direct Relevance	Total
Acadia		3,430	3,430
Alberta	23,900		23,900
British Columbia	51,778	6,660	58,438
Calgary	8,330		8,330
Dalhousie	3,000	3,430	6,430
Laurentian	6,270		6,270
Laval		67,240	67,240
Loyola	4,220		4,220
Manitoba	2,400		2,400
McMaster	42,890		42,890
Moncton	3,430		3,430
Montreal	13,720		13,720
M.U.N.	12,450		12,450
New Br.		26,270	26,270
Simon Fraser	16,390	28,470	44,860
St. F. X.	11,960	1,960	13,920
Toronto		1,960	1,960
Waterloo	6,170	37,660	43,830
Windsor		35,480	35,480
W. Ontario	34,460	7,875	42,335
York	9,700		9,700

Appendix F-2

NRC Grant to Universities 1968-69

Research Relevant to Communications
by Activity

II. Space Research and Astronomy

A. Long Term Relevance		B. Direct Relevance	Total
Alberta	19,120	5,000	24,120
Bishops	1,600		1,600
British Columbia	30,870	20,180	51,050
Calgary	50,490	79,130	129,620
Carleton		11,070	11,070
Dalhousie		1,960	1,960
Lakehead	7,810	7,350	15,160
Laurentian	3,920	13,050	16,970
Lethbridge	3,920		3,920
Loyola	29		29
Manitoba	15,190		15,190
McGill	41,450	23,420	64,870
Montreal	79,480	16,860	96,340
Nova Scotia T.C.		4,900	4,900
Prince of Wales		3,430	3,430
Saskatchewan	69,870	216,860	286,730
Toronto	19,110	64,190	83,300
Victoria		4,000	4,000
W. Ontario	3,000	146,070	149,070
York	6,470	14,000	20,470

Appendix F-3

NRC Grant to Universities 1968-69

Research Relevant to Communications
by Activity

III. Electrical Engineering

	A. Long Term Relevance	B. Direct Relevance	Total
Alberta	68,485	47,240	115,725
British Columbia	100,100	61,900	162,000
Calgary	17,520	46,580	64,100
Carleton	13,720	27,710	41,430
Lakehead	2,500		2,500
Laval	77,910	50,720	128,630
Manitoba	24,370	66,890	91,260
McGill	70,030	103,292	173,322
McMaster	47,860	57,865	105,725
N. B.	33,120	8,380	41,500
Nova Scotia	33,320	12,740	46,060
Ottawa	25,970	22,050	48,020
Polythechnique	12,250		12,250
Queens	41,170	34,960	76,600
Saskatchewan	56,170	9,800	65,970
Sherbrooke	26,570	6,500	33,070
Sir George Williams		7,350	7,350
Toronto	88,420	159,770	248,190
Waterloo	68,926	117,730	186,656
Windsor	18,720	3,430	22,150
W. Ontario	14,250	3,920	18,170

Appendix F-4

NRC Grant to Universities 1968-69

Research Relevant to Communications
by Activity

IV. Mechanical Eng.

A. Long Term Relevance		B. Direct Relevance	Total
Alberta		32,020	32,020
McGill	3,230		3,230
McMaster	3,920		3,920
Nova Scotia T.C.	3,430		3,430
Saskatchewan	31,240		31,240
Toronto		57,600	57,600
Sherbrooke	3,000		3,000

V. Pure and Applied Math.

A. Long Term Relevance		B. Direct Relevance	Total
British Columbia		960	960
Dalhousie	480		480
Manitoba	960		960
Queens	8,610	4,780	13,390
Saskatchewan	3,000		3,000
Simon Fraser		1,630	1,630
Sherbrooke		6,220	6,220
Toronto	42,570		42,570
Waterloo	2,590		2,590
W. Ontario	3,830		3,830
Windsor	3,150		3,150

Appendix F-5

NRC Grants to Universities 1968-69

Research Relevant to Communications
by Activity

VI. Computing

A. Long Term Relevance		B. Direct Relevance	Total
Alberta	12,840	3,480	16,320
British Columbia		3,430	3,430
Calgary		9,494	9,494
Manitoba	6,960	4,900	11,860
Montreal	52,120		52,120
M.U.N.	2,000		2,000
Ottawa	6,370		6,370
Saskatchewan	4,120		4,120
Toronto	59,040	8,820	67,860
Waterloo	13,520		13,520
W. Ontario	1,470	3,920	5,390

VII. Negotiated Major Grants

A. Long Term Relevance		B. Direct Relevance	Total
Calgary	125,000	114,980	239,980
Saskatchewan		100,000	100,000
Toronto		40,000	40,000

VIII. Atomic Energy

A. Long Term Relevance		B. Direct Relevance	Total
Saskatchewan	83,050		83,050
P. C.	144,500		144,500

Appendix G

Estimated R & D Dollars Expenditures in Canadian Industry Total Combined Current and Capital

CATEGORY	1967	1968	1969
1. * Telephone & Telegraph Equipment	41,773,779	40,158,159	47,170,728
2. Radio Communication Equipment	5,058,125	4,829,665	4,224,474
3. Television and Radio Broadcast and Distribution Equipment	292,747	501,680	330,000
4. Television and Radio Receivers	832,000	700,000	630,000
5. Telecommunication Wire and Cable	500,000	724,000	939,000
6. Electronic Computers and related equipment	649,900	642,400	712,500
7. Components for all of the above telecommunication equipment catagories	1,360,942	1,126,384	6,561,949
Total Research and Development Expenditures	50,467,493	48,682,288	60,568,651

Source: Electronic Industries Association of Canada.

* Includes switching, transmission and station apparatus for telephone and telegraph equipment

Appendix H

R & D in the Trans-Canada Telephone System

An excerpt from the TCTS Submission to Telecommission Study 4(b)

The Canadian telecommunication carrier industry, besides having a very high degree of Canadian ownership, has also traditionally obtained most of its technical facilities from domestic manufacturers. It is a very capital-intensive industry making heavy demands on the Canadian financial resources but has also contributed very substantially to the growth of Canadian manufacturing industry and other industries supplying the telecommunications carriers. For many years most of the telecommunication equipment manufactured in Canada was of foreign design but increasingly Canadian manufacturers of telecommunications equipment have developed their own designs and are rapidly increasing their R & D capability to support their own manufacturing operations.

The market for Canadian telecommunication equipment is largely dependent on the spending on technical equipment and supplies by the telecommunications carriers, although export sales are becoming increasingly important in some sectors.

Current experience appears to be that R&D expenditure in the order of 8 to 10 percent of total product sales is required to keep pace with the rapid advances in technology and in the resultant requirements of the public as identified by the telecommunication common carriers.

Future projections are always uncertain but it is expected that the total value of telecommunication plant of the TCTS companies will rise from $6.5 billion in 1970 to $17 billion by 1980 and $42 billion by 1990.*
This will call for a tremendous amount of new equipment and it is of paramount importance to the telecommunications manufacturing industry that the bulk of this investment in new plant be spent on equipment of Canadian design and manufacture. Very directly therefore the amount of sales of equipment to the Canadian telecommunication carriers will determine in very large measure the financial health of the manufacturing industry and the amounts this industry can afford to spend on R&D. Conversely, unless a very much enlarged R&D effort is undertaken by Canadian manufacturers of equipment for the telecommunication carrier companies, it will be necessary to rely much too heavily on

*This estimate was developed by the TCTS Companies and is in Telecommission Study 4(a)

imported designs and may indeed make it impossible to satisfy the need for technically sophisticated equipment from Canadian manufacturing sources.

In considering the need for R&D in the telecommunication field it should also be emphasized that a host of new input/output devices, business machines, computer terminals, etc. will increasingly be connected with the telecommunication carrier network. Most of these devices will probably be owned by telephone customers, and this class of equipment will probably call for a very considerable R&D effort if Canadian manufacturing industry is to compete in this sector of the market.

SPECIAL CANADIAN REQUIREMENTS

The importance of the Canadian telecommunication network is such that the very functioning of our national institutions, business, news media, and cultural activities are highly dependent on the reliable availability of these services. In a world of changing military commitments, uncertain peace, and internal upheavals in many countries it would be dangerous for the Canadian telecommunication carriers to be too highly dependent on foreign suppliers. This is particularly true of our basic telecommunication services both locally and as regards toll facilities. On the other hand Canada will never be entirely self-sufficient - nor will any other developed nation, nor is it desirable to be so. This need for reliable sources of supply goes further than a mere need to assure a continued supply of equipment and parts used in the network. Today there is a growing need for knowledgeable technical back-up from industry to the service industries as equipment is becoming steadily more sophisticated. It is often not sufficient that such back-up be provided by the manufacturing plant as it is frequently necessary to know the design intent of a particular piece of equipment - knowledge which can normally only be supplied by the development laboratories responsible for the original design.

The Canadian telecommunications carriers carry out very extensive planning activities, combining studies of technology, traffic growth, changing population patterns, ecology, industrial and business development, etc. in order to anticipate the requirement for new services, changes to existing services, network extension and modernization, expansion of services, introduction of new concepts of service and operation and so forth.

Out of this mass of planning data emerge short term and long term plans for expansion of services, construction of new plant, and a time table for these various steps. The details of this planning process may differ somewhat within the industry but the basic steps are the same. A very important part of this

planning is the technical specification of new equipment, and the overall planning of new systems. Due to the rapid advance of new technology such plans are best developed in cooperation with the manufacturing companies, particularly with the System Engineering Department of the R&D arm of the manufacturer. If any new system is to be developed in Canada, it is essential that the manufacturing companies know 5 to 21 years in advance of the requirements of the carrier companies and that extensive cooperation takes place to develop specifications, cost estimates, delivery schedules, plans for field testing and system implementation. In the case of major systems, such as e.g. the introduction of an electronic stored program switching machine, the cost of the R&D itself is extremely high and a tremendous amount of planning must be undertaken to ensure the smooth change-over to the new facility. While the risk element is correspondingly less for other products requiring less R&D or less investment in manufacturing plant it is nevertheless extremely hazardous for a manufacturer to develop new equipment without close contact with the carrier industry.

Vertical and horizontal integration of the Canadian telecommunication industry.

The existing organizational structure of the Canadian telecommunication industry has a major impact on the performance of this industry, particularly in encouraging manufacture of electronic equipment in Canada and in creating a strong R&D base for the industry.

The major organization in this field is the Bell Canada - Northern Electric complex which combines telecommunications operations, manufacturing and R&D within a single corporate structure. Another important integrated structure is the relationship between The British Columbia Telephone Company, Quebec Telephone, Lenkurt Electric (Canada) and Automatic Electric (Canada) which all belong to the same parent organization, The General Telephone & Electronics Corp. of New York, either as direct subsidiaries or through the holding company, The Anglo Canadian Telephone Company.

These organizations manufacture a wide range of telecommunication equipment for the Canadian market and for export, supplying all of the Canadian common carriers and not just their affiliated operating companies. To illustrate this point it may be useful to look at the distribution of the sales of the Northern Electric Company for the year 1969. In that year the Company had total sales of $482.5 million, of which sales to Bell Canada accounted for $248.5, domestic non-Bell $183.4, and export $50.6. Nor is there any rigid rule within any of these integrated corporations that they will necessarily be self sufficient in all areas. Thus Bell Canada will make purchases of

technical equipment from companies other than Northern Electric if a more appropriate product is available. Similarly, the B.C. Telephone Company will obtain certain types of equipment from companies other than Lenkurt or Automatic Electric, e.g. certain types of switching equipment.

By far the greater portion of Canadian R&D in the telecommunication field is performed by these integrated corporations. Thus in 1969 Bell-Northern had gross R&D expenses of $52.9 million, not counting R&D in the social sciences or on business information systems. This included both R&D performed in Canada and the value of purchased R&D. Northern Electric in 1969 performed $41.3 million R&D in its own laboratories and purchased technical information for $2.9 million, while Bell Canada performed R&D worth $2.6 million and purchased R&D for $5.9 million (from A.T.&T.Co.). In addition Northern Electric had capital expenditures of $6.2 million for R&D and Bell had capital expenditures of $.5 million.

Similarly, Automatic Electric (Canada) Ltd. is currently spending approx. $1 million annually on R&D in Canada and about $1 million annually for purchased R&D information. Lenkurt of Canada is currently spending $1.4 million on R&D in Canada and $.2 million on purchased R&D.

These figures are a guide to the magnitude of the current R&D activities in the integrated telecommunication organizations. It should be noted however that such data are never directly comparable because of the many different transfer arrangements for technical information in effect throughout the industry, thus sometimes a parent organization will charge its subsidiaries in full for license information, technical know-how etc. while in other cases such information is transferred freely without any special charges being made. The intricacy of these arrangements is illustrated by examining the Bell Canada-Northern Electric organization for R&D.

Because of the large size of this organization and its central position in the R&D field it would appear appropriate to describe briefly the main features of this corporate structure.

Bell Canada is almost entirely Canadian-owned in that 95% of the equity capital and 98% of the shareholders are Canadian. Its main operating subsidiaries are: The Newfoundland Telephone Company, New Brunswick Telephone Company, and Northern Telephone Limited. Bell Canada also has majority ownership in the Maritime Telephone and Telegraph Company Limited but is restricted to voting 1000 shares only under Nova Scotia legislation. Northern Electric Company Limited is the main manufacturing subsidiary and is 100% owned by Bell Canada. The Northern Electric Company holds controlling interest in a new corporation, Microsystems

International Limited, which has been established for the purpose of developing and manufacturing microcircuits for an international market and for use in domestic Canadian equipment. Up to the present time the R&D effort has been conducted by the Northern Electric Research and Development Laboratories with main laboratories in Ottawa and branch laboratories in Montreal, Lachine, Belleville, Kanata, London, and Toronto. These are the largest industrial laboratories in Canada, employing more than 2,000 persons, and performing R&D covering most of the telecommunications field. The establishment of these laboratories as a separate company has been planned, and preliminary steps have been taken towards the creation of Bell Canada - Northern Electric Research Laboritories. This would give the Laboratories a stronger voice vis-a-vis Bell and Northern, and it might also be an advantage for non-Bell telecommunication carriers to be able to contract directly with the Laboratories for R&D in support of their operations and planning.

Northern Electric was reorganized in 1969 essentially along product lines. Thus both marketing and manufacturing of Switching Equipment were combined in one Company division, while similarly structured divisions were established for Transmission, Wire and cable, and Apparatus, respectively. The product line organization is somewhat modified by the establishment of a separate division for International Operations and another for Distribution Sales which will provide special marketing assistance and services for the product line divisions. Under this organizational concept each product line division will work with the R&D Laboratories and with Bell Canada in determining R&D programs for each product line and will provide funding in support of such R&D. Such program determination is mainly performed by Product Planning Committees, one for each product line, with the Systems Engineering Department of the Laboratories providing strong support through the preparation of a Prospectus for each project, coordination of market forecasts, technological data etc. The principal involvement of Bell Canada is through the Planning and Research Department of Bell Canada HQ. Microsystems International Limited will also undertake a very agressive R&D program, part of which will be performed by the R&D Laboratories and part by MIL directly.

As previously mentioned, Bell Canada is particularly interested in exploratory development work which is performed by the Laboratories in advance of actual development work to provide insights and data for use in planning future development projects. Bell Canada funds 70% of such exploratory R&D with Northern Electric paying the other 30%. Development costs are in general recovered by Northern Electric through sales of equipment.

Prior to 1957 the Western Electric Company of the U.S. held a 43.6% interest in Northern Electric, the remaining stock being owned by Bell Canada. Partly as a result of the Consent Decree entered into in 1956 between the U.S. Department of Justice and the A.T.&T. Company, Western Electric sold its investment in Northern Electric to Bell Canada. Bell Canada acquired 89.97% ownership of Northern Electric in 1957, increased to 99.99% in 1962, and 100% in 1964.

Up to 1959 the Northern Electric Company had operated mainly as a manufacturing plant using design information originating with Western Electric Company and Bell Labs. It was felt this was not a desirable permanent situation, and in 1955 a study was made by Dr. C. J. Mackenzie, former President of the National Research Council, on the establishment of a centralized research and development laboratory. The R&D Laboratories were formally established in the summer of 1958.

Under a Service Agreement entered into in 1923 with the A.T.&T. Company on Services, Licenses and Privileges, and succeeded by a Service Agreement of 1949 which is still in force, Bell Canada has access to results of Bell Laboratory research and advice and assistance from the A.T.&T. Company on a wide range of matters, including general engineering, plant, traffic, operating, commercial, accounting and other matters and has the right to furnish such information to other operating companies in Canada. The agreement also gives Bell Canada the right to use of Bell Lab. and Western Electric patents and licenses and it may extend this right to its subsidiaries. Under agreements between Bell Canada and other Canadian telephone companies these companies also receive such information (excluding patents and licenses) but all companies do not contract for the same amount of information. It should be noted that the information received under the Service Agreement is not design information. It serves a very useful purpose in facilitating coordination of North-American telephone services and keeps us abreast of developments within the Bell System but does not contain the detailed manufacturing information nor design calculations and manufacturing know-how.

Northern Electric has for many years had a Patent License Agreement and a Technical Information Agreement with Western Electric. Prior to 1959 Northern Electric under the terms of the Technical Information Agreement had rather free access to Western Electric design information and manufacturing know-how. When the T.I.A. was renewed in 1959 for a further five years, and again in 1964, the amount of information obtained by Northern Electric under the T.I.A. was greatly reduced, and the economic terms became much less favourable. Essentially, Northern Electric is now in the same position vis-a-vis Western Electric as any other manufacturing company, as any manufacturer may obtain patents and

technical information from Western Electric on equal terms under the Consent Decree of 1956. The flow of information under the T.I.A. entered into in 1969 between Northern Electric and Western Electric has dwindled to a trickle and mainly comprises certain types of information on electronic switching. No manufacturing know-how is included under the T.I.A.

The Technical Information Agreement may be considered a straight commercial agreement of decreasing significance to Northern Electric as most of Northern Electric's new designs are based on independent Canadian R&D. It will, however, be of some importance for some time to come because so many of Northern Electric's current products are based on original Western Electric designs or make use of W.E. patents.

The main significance of the A.T.&T. Company - Bell Canada Service Agreement to Northern Electric is that under the terms of this agreement Northern Electric makes use of W.E. patents without paying royalties on sales to Bell Canada or its operating subsidiaries but has to make a charge to cover royalty payments on sales to other companies if any W.E, patents are used in equipment sold.

It will be evident from the above that the special relationship which once existed between Western Electric and Northern Electric has undergone a drastic change in the past ten years and that today nothing more than a straight commercial relationship remains. Fortunately, the R&D capability of Northern Electric has now expanded very significantly but even then it is beyond the resources of that organization to generate designs covering all the requirements of the operating industry. The most important thing is to concentrate efforts on those projects which are really important. A major concern in preparing an R&D program is therefore to make the right make or buy decisions.

In 1969 Northern Electric's performed R&D amounted to approx. $41.3 million while the value of information purchased from Western Electric was $2.9 million. The corresponding figures for Bell Canada were: Performed R&D $2.6 million, purchased R&D (From A.T.&T. $5.9 million). The R&D budget of Northern Electric has been increasing at a rate of $5 million annually for some years now and should continue to do so over the next five-year period unless the current shortage of funds continues and forces a stop to this expansion.

Nor should it be forgotten in discussion of R&D being performed by the R&D Laboratories that some very worthwhile R&D is also being undertaken directly by Bell Canada. Such telecommunications carrier R&D is normally concerned with special assembly work to engineer a system to suit a specific function

but some larger efforts such as the SWAP system development, which is a radio paging system for wide area use, have been undertaken by Bell engineering staff. A considerable amount of development work is also being done in the operating industry in the area of improved technology for burying cables, improved maintenance practices, etc. Bell Canada is also actively engaged in research in the demographic and social science field, in cooperation with the University of Toronto and the University of Montreal.

Source: Trans-Canada Telephone System.

Appendix I

Industrial Research Institute Programs

In 1965, the University of Windsor approached the Department of Industry, with a preliminary proposal, endorsed by the Windsor Chamber of Commerce for the establishment at the University of a research institute to serve local industry. During 1967, grants were approved to assist in the establishment and maintenance of Industrial Research Institutes at Nova Scotia Technical College, McMaster University, the University of Waterloo, and the University of Windsor.

Objectives

All are non-profit organizations to provide scientific services to industrial firms and other institutions, which are unable to maintain research facilities and personnel of their own. The objectives were to help alleviate the shortage of scientific and technical resources, to foster a closer relationship between universities and industry, to improve the universities' understanding of the problems of industry, to help industry become acquainted with the latest pertinent scientific and technical development. This is done through negotiation of grants or contracts between industry and universities to cover particular problems or problem areas.

Program Expenditures and Results

The Departmental expenditures are expected to be $168,000 for the year 1968-1969. In the previous year they totalled $84,206. By January 31, 1968, grants totaling $500,157 had been authorized.

Assistance under the program takes the form of grants to cover the costs of establishing and administering Industrial Research Institutes, including the salaries and wages of managerial and administrative staff, office rentals and supplies, and similar administrative expenses, normally for an initial period of three years.

Staffs have been acquired by these institutions and ongoing contracts have been established with industry and local governments; a number of contracts have been completed and active research is under way for others. The sizes of the research contracts have been generally small but have totalled $800,000 of which $300,000 was from governments. There is some element of specialization in the work, oriented towards local environment. The volume of contract research is growing at a rate that is considered satisfactory for this stage of the program. The

Institutes also provide educational services for industry in the form of specialist training, refresher courses and seminars.

There have been proposals from a number of other universities to establish industrial research institutes.

Appendix J

The R&D Committee

of the

Electronic Industries Association of Canada

This committee was formed several years ago to deal with R&D matters of concern to the electronic and telecommunications manufacturing companies in Canada. It is made up of representatives from member companies of the Electronics division, who produce professional or capital equipment, and who carry out most of the R&D activity. Their interests range from radio and television broadcast and cable systems, microwave and radar, land, air and maritime mobile equipment, navigational systems, to electronic test and industrial equipment, telecommunication switching and apparatus systems, computer and peripheral equipment.

Several briefs have been prepared by this committee for submission to the government, including those presented to the Senate Committee on Science Policy, and to the Department of Industry, Trade & Commerce. It has actively studied various R&D assistance programs with particular emphasis on IRDIA. It continues to look for ways and means of providing an effective liaison with government departments, especially where consultation before legislation is drafted is appropiate. Because it is specifically oriented towards electronics and telecommunications, it represents the best presently organized interface with this segment of the Canadian manufacturing industry on R&D affairs.

Source: Electronic Industries Association of Canada

Appendix K

The R&D Committee

of the

Canadian Manufacturers' Association

This committee was formed in 1961 to consider matters of common interest to CMA members in the R&D area. It was inactive for several years but was resuscitated during 1969 because of the need for better communications between the manufacturing industry and the government on R&D matters. Because the CMA membership comprises over 7,000 industrial companies, the Committee represents an extremely broad base of manufacturing interests and viewpoints. Its member companies are large and small, Canadian or foreign owned or controlled.

During the last eight months, this committee has devoted itself to work in the following categories:

(a) Statistics -- working with the Dominion Bureau of Statistics.

(b) Definitions -- what is meant by R&D and innovation?

(c) Government R&D Assistance Programs: -- IRDIA, PAIT, DIR, IRAP, IDAP, IMDE, DIP, NRC, Fellowship Programs.

(d) R&D problems of small manufacturers.

(e) Technical Manpower.

(f) Business spin-offs.

(g) Relation between inventors and investment sources.

(h) R&D and profits.

(i) Government Reports O.E.C.D., Lamontagne Committee, etc.

The committee has 46 members, mainly directors of research or engineering, or other senior company officials interested in R&D matters. It has already held several meetings to which senior government officials have been invited, and much useful and informative discussion has resulted. It is available at any time for round-table discussions of either general or specialized subjects in large or small groups.

The industry believes this committee can perform a very important role for the promotion or R&D in Canada and thus promote the economy. It can act as a sounding board for the government for all R&D matters of general interest to industry. Since its members represent most, if not all, of the industrial R&D organizations in Canada, it can prepare briefs to the Government which are widely representative of industrial thinking.

Appendix L

The Canadian Research Management Association

History, Constitution and Purpose:

The Canadian Research Management Association was formed in 1962 for the prime purpose of improving personal contacts across the country between individuals responsible for the management, as distinct from the execution, of research in government, industry, university and institutional organizations. Membership is by invitation and now totals approximately 124, of which the percentage in government, research councils, and institutes, universities and industries are approximately 4 1/2, 6 1/2, 19 and 70 respectively.

The common interest among members is in improvement of techniques of research management. The Association operates on a small budget, with no paid officers, and meets once a year for presentation of papers, discussions and informal seminars, and appraisal of research activities in the region. Meetings have been held in Montreal, Ottawa, Toronto, Vancouver, Edmonton, Sarnia and Halifax. In 1970 the Annual Meeting will be in Montreal, and in 1971 in Saskatoon.

Because of its broad representation, the Association does not seek a consensus, or expression of views in public, or the drafting of policy statements concerning the conduct of research in Canada. Rather it provides a means for expressing, evolving and analyzing ideas, leaving each member free to act later in the interests of the organization to which he belongs.

Appendix M

SCITEC

SCITEC is the "Association of the Scientific, Engineering and Technological Community of Canada", officially organized in January 1970. Its founding resolution states its objective: "To marshal the scientific, engineering and technological community to provide leadership, to communicate, co-operate and work within itself, with government and the public in the national interest, in those areas in which it can make a competent contribution."

The provisional SCITEC constitution provides for both society (or association) and individual memberships. Members may be affiliated with either a French-speaking "Assemblee" (ACFAS) or an English-speaking "Congress", which in turn are represented by a 29-man council. This provisional council includes members of the Chemical Institute of Canada, the Canadian Association of Physicists, the Agricultural Institute of Canada, the Biological Council of Canada, the Canadian Federation of Biological Societies, the Canadian Medical Association, the Canadian Dental Association, and the Engineering Institute of Canada, all representing English-speaking Canada. The French-speaking scientific community will have seven representatives drawn from l'ACFAS. Three social scientists, a University of Toronto graduate student, an under-graduate from the University of Alberta, and a University of Montreal student round out representation on the present council. The executive held its first formal meeting in Montreal on February 18th, 1970.

SCITEC sees communications within the community it represents, with the government, and with the general public as its most important function.

Appendix N

Technology, Innovation & R & D

Improvements in applied technology are basic to a nation's economic growth for the traditional economic inputs of labour and capital are no longer, by themselves, enough. What is critical is the application of these resources to productive purpose by means of modern technology. The effecient utilization of technology is the source of growth and vitality for individual enterprises, industry sectors, and entire nations. Studies indicate that some 90% of all productivity increases and 70% of measured economic growth in the United States, over the preceding 35-50 years, could be attributed to technological change. New technology has created new products and new industries, and there is a universal expectation of a continuous flow of new products and a continuous change in the quality of life. Certain industries, including communications, may be defined as technology-intensive with high dependence on a continuous innovative activity.

Innovation is a man-created activity and will not generally occur in industry except under one of the following circumstances:

> A general incentive or pressure for a firm to innovate; this may stem, for example, from the anticipation of increased profit margins, turnover, or growth, or a solution of its labour problems.
>
> The pressure of competition; acceptance of the need of innovation, once other firms have done so in order to survive.
>
> Ability to identify technical and connected opportunities for innovation, available for in-house capabilities, or purchasable externally.
>
> Disposal of adequate managerial, organizational, technical, and financial resources.

In the Canadian environment, the speed and effectiveness of technical innovation depends primarily on the competence and initiative of private firms. Government actions and policies, while aimed at encouraging innovation, rely primarily on initiative from industry.

The importance of science and technology in shaping a nation's future has been recognized and emphasized in recent years. Policies have accordingly been formulated and implemented, one of which is the promotion as both the source of

innovation and the means of adjusting to it. This is reflected in the growth of resources devoted to R & D by developed countries, and the growing range of national objectives for which R & D is supported by government. The rapid growth in R & D is fairly recent; commitment to the support of R & D on a grand scale arose in large part from specific defence requirements, and was accelerated during the 1950's. But it is only in the past ten years that R & D and national science policies have come to reflect a broad-based public interest in accelerating the rate of technological change and economic growth. This has forged close links between industry, universities, and governments.

However, it must be emphasized that, because of international technology flows, it is not necessary for countries or companies to generate all their technological knowledge internally. Multinational companies are dominant in transferring industrial technologies and exchanging large quantities of technical goods and services between affilliated companies in various countries. Other institutions such as joint technical ventures, co-operative R & D programs, and cross-licensed enterprises are the other means of acquiring R & D. In Canada a large contribution to innovation is made by foreign companies which impose their technological, competitive, and management standards on their Canadian subsidiaries.

The corporate view of the R & D process is one of continuous operation with an object of providing a a steady flow of new and improved products and processes, including the mangement process. R & D has come to be accepted as part of the production process, subject to planning and budgeting, control and optimization. The activity is worthwhile when the monies expended for R & D are less than the resulting savings through improved production or managerial processes, or through additional revenues that may accrue from production innovation in terms of new products or improvements.

Three elements can be distinguished in the introduction of a new or improved process or product-

- establishing the technical feasibility of a new or improved product or process;

- introducing a new or improved product or process into the economy for the first time;

- innovation by imitation, when a firm introduces products or processes already introduced elsewhere.

Research and Development undertaken by a corporation may result in:

- technical success.

- product or process change or improvement.

- new product or process.

Success in any of these enables a corporation to reduce costs, as for example through savings in labour or material and economies of scale, and thereby to increase profits, to increase sales and exports, to rely less on on borrowed technology, to increase revenues through sales of technology, or to improve competitiveness.

R & D need not always be undertaken solely to create or improve specific products but may also be undertaken to gain experience and knowledge of a kind which makes possible the adoption of a technology, past or future.

The decision to commit corporate funds to R & D expense is tending to become systematized. Both quantitative and subjective measures are used to evaluate project proposals and their feasibility. They include availability of technical skills, corporate objectives, and technical, manufacturing, marketing and other economic implications.

Studies indicate that about four out of every five hours are devoted by scientists and engineers to projects that do not reach commercial success. Data on the percentage of projects that result in new products or processes show an average of 30%. According to the studies by Booz, Allen and Hamilton, based on surveys among major companies in the same industry, the efficiency range varies from less than 6% to 84%. Efficiency was defined as the percentage of the companies' R & D expenses devoted to successful products. On an average across all companies reporting data, only 45% of the terminated projects result in increased profitability.

The sales-volume/profit-pattern and the timing of the product life-cycle varies by product and industry. The result is that systematic evaluation of R & D results is most perplexing. The concept of efficiency requires a determination of but leaves open the decision of what cost elements should be taken into account. A determination of efficiency has no meaning without reference to effectiveness in achieving specific objectives at particular times, and cost may not be the only or the most relevant consideration.

The effectiveness of R & D can be determined by associating the quantitative measure of its cost with subjective notions of research achievement, which may relate to various

objectives, some directly rated to profit, others to different corporate ends (i.e., manpower training).

In general a systematic methodology for evaluating R & D in these terms is lacking. Economics, sociology, politics and other disciplines are involved. It is also difficult to justify R & D by cost benefit analysis. Therefore the argument for support must be based to some extent on faith in intangible values.

A general impression prevails that innovation and R & D are the same phenomenon - that, if you have more R & D you get more innovation. Innovation is better described as a total venture, not just R & D. In most projects R & D is only 5-10% of the total process. For innovation, it is not true that the only available incentive is that of underwriting research and development. In fact, concurrently with the underwriting of R & D expenditures, measures also have to be undertaken to stimulate a high rate of investment in the industry and in the economy, so that new technical knowledge can be rapidly incorporated in the production process.

Few companies think of themselves as designed deliberately to foster innovation. In certain sectors where there is a need for a breakthrough,as communications, new collective needs of the community may not be satisfied through R & D activity alone. Only a small percentage of R & D activity in corporate laboratories, even when directed to product development involves breakthroughs; it is mostly application of known skills and procedures.

In the general innovative process, industry and government seldom concentrate on radical technological changes that may sweep aside existing practices and open new opportunities. R & D establishments usually lack a systematic methodology for evaluating such changes in which economics, sociology, politics, and even ecology are involved and affect its diffusion.

In telecommunications, innovation is required if output is to grow and the share of the market has to be cultivated. It is a large-equipment sector where innovation will have an important effect on total environment and performance. The sector is of strategic importance with regard to the employment of scientists and engineers. Few other countries are as advanced; therefore the problem is not to rely mainly on foreign technology or to make an effort to catch up with other countries.

Having identified the need for development in telecommunications it would be necessary to develop the necessary unified program of research and application, after having defined the technological and economic environment. A laissez-faire

concept does not lead to optimum allocation of R & D resources for the common good and future growth. Future growth is not to be viewed in only the economic sense but in the sense of possibilities and potentialities of a given society.

A present handicap is the absence of leverage, through procurement contracts, to influence the level of R & D in the industry. In the absence of a national strategy for industrial development, it would be necessary to develop a framework for the telecommunications industry if R & D endeavour is to increase and give results.

An example is the new world of opportunity that is being created in the field of information science. It should be possible to provide a totally new information and entertainment service for the individual user. Despite the enthusiasm for such a network at all levels, neither the industry not the government has yet produced the grand design needed to tie together the multilinks of different information and entertainment network schemes.

In the absence of such planning, the companies would have to maintain a costly program of R & D on a continuous basis, aimed essentially at product improvements and updating. There is no need for external stimulus for the encouragement of such R & D. Competition would require companies to improve products and to reduce cost in order to survive, and it is not the R & D programs but the heavy expenditures on equipment, marketing, and forced obsolescence which would continuously affect their capital resources and profits.

Source: J. Moorjani, Department of Industry, Trade and Commerce.

Appendix O

Why Canadian Companies Engage in Communications R and D

The purpose of industry is to produce and market manufactured goods or services. To achieve the primary purpose it also aims at providing employment for professional people and for a diversity of skilled, semi-skilled and unskilled workers. It organizes the efforts of this total work force, coupled with the utilization of raw materials and capital equipment, to achieve this primary purpose.

The basic reasons for carrying out R & D programs in industry vary from company to company, depending on size, ownership and product or service interest. In one way or another, however, the following generalizations apply to most science-based or technologically oriented companies.

All the complex and diverse operations of industry must be conducted efficiently in order to provide a satisfactory return on the capital invested in the enterprise. This can be utilized either for expansion of the business, when market circumstances make this desirable, or to pay a dividend to the stockholders, or both. The achievement of this 'return on invested capital' is a major objective of busines which, unfortunately, is often misunderstood or misrepresented by some modern critics of the industrial scene. From the point of view of the stockholder, it is to some extent comparable to the interest paid by the chartered banks for deposits in savings accounts. From the viewpoint of the company it is also analogous to a management fee earned by virtue of good management in the conduct of the business operations. Finally, it is on the basis of these 'profits' derived from business operations that corporation income taxes are paid and therefore, if the return on invested capital declines, so also will government revenues derived from industry.

Despite some of the failings attributed to industrial operations, which are receiving increasing publicity at the present time, it is fair to say that, on balance, in the pursuit of its objectives industry has contributed not only to national economic growth but also to the quality of life. It does this directly through the products or services it makes available to the public, and indirectly by generating government tax revenue. Together, these represent a very large proportion of government income and, to the extent that such revenues are used to improve the quality of life in a country, industry is making a very substantial contribution. Finally, less tangibly but no less importantly, industry contributes to the quality of life by

virtue of its social links with the community and the kind of total environment which it establishes for its working force.

From the customer's point of view the products of competitive industry must be reasonably priced. This is also an industrial objective, since a much wider market is usually open to a lower priced product. The customer also expects quality in the products he buys, and no industry will survive long if its goods are shoddy. The customer has also come to expect improvements and advances from year to year in the products available. This is especially true now, when technology is advancing rapidly. Improvements in performance, quality, or price are all attractive to a customer or prospective customer. All the interests of the customer are protected under a free-enterprise system in which competition is strong. For each company to retain an acceptable portion of the market it must continually strive to remain efficient in all its operations, lowering its costs so that its products or services are offered at competitive prices, still leaving a satisfactory return on the capital invested in the company. The competitive environment also forces all companies to maintain the quality of their products and their performance characteristics, and to look to the future, engaging in product improvement and the marketing of new and advanced models, keeping fully abreast of the state of the art. The attainment of all these objectives is dependent on the R and D undertaken by industry.

Some service industries are virtual monopolies, where prices to the customers are regulated by government. Since this procedure limits income, such industries are under particularly heavy pressure to be efficient in order to make returns on investment which will attract new capital required to meet the demand for increased services. This pressure is passed on to the manufacturing companies supplying monopolistic service industries, and it is imperative that they sell competitive products at the lowest prices consistent with making reasonable returns on their own investment. To accomplish these objectives supplying companies must undertake well organized programs to reduce costs and increase efficiency. If they are to maintain inventories of modern equipment suitable for sale in both domestic and foreign markets, they have no option but to undertake comprehensive R & D programs.

If an industry is engaged in manufacturing and marketing a product, from time to time production problems will arise which call for engineering assistance in their solution. This engineering assistance will often necessitate research before it can be effective, and this research will usually be of an "applied" rather than a "basic" nature. In general, the more technically advanced the product, the more sophisticated the

production engineering support will have to be, and the more highly qualified the engineering personnel.

Again, to keep such an engineering team on its toes and abreast of advancing technology, it is essential that they devote part of their time to research programs of direct relevance to the field of technology with which the company is generally concerned. Such research programs would most likely be aimed towards the development and ultimate production and marketing either of improved hardware, or of completely new models with such qualities and characteristics as will make them much more attractive to customers and potential customers than either the older products or the products offered by the competition. Here again, as in all cases, it is the needs of the customer which really determine what a company must offer in order to be successful in the market. The successful entrepreneur needs all the skills, knowledge, and past experience available to him in correctly assessing what the customer needs.

In the course of providing production-engineering support, engineers and scientists will recognize the possibility for improvements in products, based on some redesign to incorporate recent advances in technology. Here again development programs are essential. Much more radical product changes may appear possible if research programs are undertaken to explore completely different technological approaches. Decisions must be made at the management level, and it is evident that the degree of risk is proportional to the extent that the new products depart radically from the old. Thus the evolutionary process within a company originates most frequently from the engineering team engaged in product support. The pressure to develop new products may derive from commercial intelligence about what the competition is doing or may be going to do, or what the customer is beginning to demand, or what it is thought that he will be demanding in the near future. In such cases, the sales and marketing departments, or the senior corporation management itself, may identify and promote or initiate the required R&D programs. Since it is accepted that all products have a limited life-span and will, sooner or later, be replaced, companies must themselves be engaged in advancing the technology, to an extent that enables them to lead rather than follow in the development cycle.

Since market demands may give rise to fluctuations in business activity (and this is very true for defence requirements), most companies attempt to stabilize their business by diversification of products and development of broad markets. This is often difficult and calls for conscious and deliberate management decisions to initiate R&D programs leading to products quite different from those being currently produced, although usually based on the same or closely associated technologies. It

is not common for companies to be able to achieve success in diversifying their activities into fields employing technologies radically different from those to which they are accustomed, other than through acquisitions or mergers.

In the complex world of today the technology utilized by industry for innovative purposes comes from a variety of sources. Some is self-generated, some is imported from parent or associated companies, and much is derived from current publications or past contributions to the existing total pool of knowledge.

Industrial companies, especially in Canada, do much more applied R&D than basic research. To some extent basic research is a cultural activity which adds to our fundamental scientific knowledge but cannot usually be economically justified on a large scale within industry. Because of its association with the production of new scientific knowledge and the learning process, it is an activity best suited to the university environment. To some extent basic research in certain areas is appropriate within government laboratories where, as in the universities, the generation of short-term results leading to the production of new goods and services is not required. Modern research tends to be highly sophisticated, involving specialized and expensive facilities and test equipment which can be provided only through large expenditures by or in government, or by special grants or endowments to universities.

Between 50% and 80% of the products of most technology-based industries did not exist ten years ago. These products are the result of applied R&D either performed in Canada, or based on imported technology developed from foreign programs. Canadian companies will have to import much of their technology for many years to come, and that the transfer and application of this technology requires a trained staff competent to make technical decisions. Such competence, and the ability to make decisions which will best utilize a company's resources, cannot usually exist without an in-house capability in applied R&D.

Diversification and the development of a broad product line can be achieved by importing technology, but market requirements in Canada are often sufficiently different to necessitate special design requiring additional applied R&D. The exploitation of export markets generally demands designs somewhat different from those used domestically, and here again applied R&D is required in Canadian companies. It is becoming increasingly apparent that only those companies which maintain a dynamic and progressive applied R&D capability will be able to meet the challenge from foreign competition in both their internal and overseas markets. Nonetheless, industry is now recognizing that some of the basic research necessary to ensure

the continuity of business must be done in industry, where it can be product-or mission-oriented. The amount of basic research in Canadian industry can be expected to increase in future but, even if product or service development is vastly increased, Canada will continue to rely heavily on the results of foreign research.

Hitherto, a significant factor in coordinating R&D activities has been the pivotal effect of the government grant or aid programs. An EIAC representative pointed out that the Department of Industry, Trade & Commerce makes a very real effort to coordinate industrial applications. In making grants it has attempted to establish whether companies have the resources for any determined research project; it also encourages work under way in the laboratories, and assists in marketing the results of that research. As previously noted, the NRC university research grant program is a focal point in obtaining information on research activities in universities. However, it was ageed that there is really no central clearing-house affording a total picture of R&D activity in the communications sector, and singularly missing is some form of active information exchange between research projects in differing but allied fields of activity. The industry representatives on the Project Team noted particularly the difficulty of receiving and maintaining an accurate flow of information on research activities undertaken by government departments in their own laboratories.

The exchange of information on research activities is inhibited by the problems of proprietary information in industry and, in some instances, of security in government. As excuses, both are often chimeric. There is no doubt that the lack of information, particularly between one research manager to another, contributes to the inefficient utilization of resources, and deflects the coordination of research activities with specific goals.

The coordination function of government grant programs is really one of its secondary objectives in promoting a higher degree of effectiveness in R&D activity. The main thrust of the IRDIA and PAIT programs has been to develop a higher degree of technology and R&D capability in Canadian industry; to get, as the current phrase goes, 'more bang for the buck'. In discussing the effectiveness of present research and development policies, the EIAC representative made the following comment on government grant and aid programs:

> "The generally low level of profits in the telecommunications manufacturing industry makes it impossible for most companies to fund their own R&D programs. Many companies are now unable to afford their share of jointly funded programs, though this situation has recently been improved by the change in the

regulations of the PAIT program whereby companies no longer have to pay back the government share of successful programs. The Trans-Canada Telephone System is a notable exception to this state of affairs as it can afford to sponsor some R&D in fields of direct interest, though this is due to the volume of its business rather than to the percentage profit it makes, since its rates are subject to Parliamentary regulation. The universities also need considerable government assistance to augment their own very limited resources and one benefit from this could be to encourage them to do more applied and less basic research. The government must share the overheads as well as the direct costs of research programs and a review should be made of the support afforded graduate students and of the salaries paid to junior faculty or senior research associates. If this is not done the drain will accelerate.

The initiative in all these programs comes from the company or the university concerned whose task is to convince the responsible government department of the need for the proposed research and development of funds and of its ability with available personnel and resources (sometimes augmented by capital grants) to carry the work to a successful conclusion within the time frame and financial aid requested.

This is fine, except that it does not go far enough. Certainly neither the universities nor industry would accept complete government direction of their R&D activities, but there are very few direct government R&D contracts in either of the non-government sectors.

Government must have strong in-house R&D to keep it up to date with technological progress so that it can assess trends, decide priorities, and coordinate national R&D efforts, but there should be a greater willingness to make use of expertise, regardless of where it exists, in the country. It is therefore necessary in Canada to have major fully funded government programs extending over periods of three to five years to enable industry and the universities to establish and maintain research and development at an adequate level."

Considering the present spread and organization of R&D activities, it seems desirable that coordination for the purpose of monitoring the level of activity, exchanging information, and analyzing the results so that they can be related to national goals should be the prime responsibility of the government. As previously stated, government-supported aid programs now contribute greatly to coordination at the information level,

although there has been little leadership from the government in establishing goals for research and development in the communications sector. The difference between coordination and planning was noted in discussion, and it was suggested that there was little likelihood that R&D activities could be so tightly coordinated as to produce a single end result, or indeed that this degree of coordination should be sought for. In the long run the objective should be that each research centre - whether in government, industry, or a university - would establish its own objectives, paying due regard (if only through enlightened self-interest) to the contribution to be made in meeting national goals.

Source: Electronic Industries Association of Canada

Appendix P

Reasons for Conducting Research and Development in Universities

By a series of historical accidents, universities have acquired several functions, the most obvious of which are, teaching and professional training, the difference being primarily one of attitude. Other functions are the additions to the accumulated store of man's knowledge through research and similar activities, and the ability to speak authoritativly in academic matters by testing for professional certification.

At present it is generally agreed that the best performance in any of these activities cannot be achieved by concentrating on that activity alone -- the best teachers, from the university point of view, are those who are up to date in their subject, and who maintain contact with the latest developments through research. In many subjects it is necessary to maintain a close contact with the outside world by, for example, private practice in the professions, or by consulting in the sciences. These activities produce many internal conflicts of interest.

However, if there is one consideration which overrides all others in a university of repute, it is the constant striving for excellence. The path to advancement in the university hierarchy is by demonstrated personal excellence in all the functions listed above. This is an individual performance, and it has the consequence of ensuring that the research activity of each academic is a part-time effort, although often much more than a half-time effort, and that the judgment of an individual academic staff member in research is based on his ability to conceive a new research project and to carry it out.

There is a tradition, embodied in the slogan "academic freedom", that universities shall not dictate the nature of the intellectual activities of individual faculty members, and this is consistent with the practise in the assessment of performance, that it is the individual's judgment in these matters which is being assessed, and that the individual must have complete freedom to choose what line of research he should pursue.

University administrations cannot tell an individual faculty member what kind of research he should do. The only ways in which research interest in the university can be directed by the administration are by hiring as faculty members people with common interests, and by providing facilities in a certain field (although this may not be as effective as may often have been

thought). Of course, a faculty member may change his interests, and almost nothing can be done to stop him since he is usually protected by "tenure". This is of course one aspect of the concept of academic freedom.

In addition to his advancement in the university hierarchy, an individual faculty member usually takes great interest in his reputation in his wider professional community, and his reputation outside the university is almost always taken into account by the university in assessing his total performance.

Universities are not places where a concentrated effort can be mounted using a large team of scientists and technicians on any particular problem. Since the same research activities are used to train graduate students and are part of the teaching function of the university, such projects cannot be carried on with the same efficiency as in an institute devoted entirely to research.

Source: Dr. J.M. Daniels, University of Toronto.

Appendix Q

The Role of Systems Engineering in Telephone Communications

The term "Systems Engineering" has a variety of meanings attached to it. In different places and different circumstances many of these meanings are equally useful. It is now recognized that systems engineering is an essential activity in most parts of the communications industry, but this discussion will be confined to systems engineering as it applies to the telephone network. The scope and complexity of the telephone communications network undoubtedly influenced the early introduction of systems-engineering techniques and philosophies.

Historically the telephone network has been considered to comprise four major classes of communications equipment.

(1) Station Apparatus - comprising a wide variety of input - output devices, including the telephone set located on the user's premises.

(2) Outside Plant - comprising a variety of wires and cables, with their associated mounting hardware and supporting structures, used to interconnect separate points in the network.

(3) Transmission Equipment - used to amplify and/or multiplex a large number of circuits onto a wire, guided wave, or radio facility; included are equipments for amplifying or regenerating the transmitted signal on the facility.

(4) Switching Equipment - used to select an available path through the network under the control of the user, to permit connection of the calling party to the called party.

These somewhat arbitrary definitions have served their purpose well for many years, but as technology advances the differences between these four kinds of plant are becoming increasingly difficult to distinguish.

One of the principal activities of systems engineering is to optimize the economic and technical design of the overall network, taking into account both initial capital requirements and ongoing operating and maintenance expenses. This involves the introduction of changes to permit existing services to be

handled more economically, the introduction of new services to increase usage of the existing network, and anticipation of the changes required for future service requirements that would exceed either the capacity or the capability of the existing network design.

On account of the size of the capital investment embedded in the existing network, and of the universal nature of network service requirements, it is seldom possible to design an entirely new network. All future changes must be considered in the context of what already exists. The future must be made compatible with the past.

In the introduction of new technology into any one of the four major kinds of plant indicated above, the existing characteristics of the other three place restrictions on what can be done with the one under consideration. Therefore it is generally necessary to consider advancements in all four classes simultaneously; the establishment of trade-offs, and the definition of interface characteristics and functions to be performed by each is a major objective of systems engineering.

While systems engineering is a relatively small group accounting for only about 5% of the total R & D effort, it represents the tip of the R & D iceberg--it guides and directs the rest of R & D in determining what should be done, why it should be done, and when it should be done. It assures that the efforts of individual development groups are co-ordinated towards the establishment of an efficient economic overall system or network of communications.

Perhaps Peter Drucker was thinking of the importance of systems engineering when he said:

> "Success is more dependent on doing the right things than it is on doing things right."

The fundamental role of systems engineering is to determine, from the millieu of development opportunities, the limited number of projects that should and can be undertaken, and in this way to provide guidance in establishment the scope and content of R & D programs.

Since the systems engineer forms a sort of bridge between the user and the developer, he must be capable of interpreting the state of the art and the development capabilities to the user; telling the user what can and cannot be done at this time and why. He must also protect the user's interests and interpreting their requirements to the development engineer. It is therefore essential that system engineer's

relationships with both groups be maintained on the highest possible level.

The process of project selection is complex, and there are no easy rules by which the value of one specific project versus another can be determined. There is, however, a variety of criteria which must be considered in each case, and the trick is to determine what weighting should be applied to each factor in each case.

Some of these criteria are as follows:

--- Corporate objectives
--- The Need
--- The Market
--- The State of the Art
--- Competition
--- Resources
--- Technical Feasibility
--- Economic Feasibility
--- Timing

--- What?
--- Why?
--- Why Now?
--- Why This Way?
--- How Much?

The systems engineer is charged with the responsibility of protecting the integrity of the existing communications network in terms of its quality and its ability to continue to provide communication services now and in the future.

Source: Northern Electric Company Limited.

Appendix R

The Economics of Research & Development

Synopsis

This paper presents a brief discussion of the economics of Research and Development in the Communications Industry, in a limited sense. It does not concern itself with the importance of R & D in the national economic context, but is confined to the questions of a) costs of R & D related to new products and b) the economics of decision-making in R & D programs.

Relationship of R & D Costs to Total Costs of Innovation

In order to discuss the aspect of R & D economics, some definitions are necessary. For our purposes, the following will be used:

R & D Costs: The costs incurred in the innovation process up to the point of creating and producing a feasibility prototype of the product, with all performance characteristics substantiated, and manufacturing drawings available. Innovation Costs: The total costs of creating a marketable product. These include the costs of R & D, and the costs of engineering for production, tooling, manufacturing set-up, and initial marketing planning. There is no simple rule-of-thumb relating costs of R & D to total costs of innovation. The kind of manufacturing system (production line or job shop), peculiarly suited to the product has a heavy bearing on such a ratio and is perhaps the most important single variable.

(a) Products which are amenable to (and justify) the establishment of a production-line manufacturing system, have a heavy proportion of innovation costs in the non-R & D phases. That is, the costs associated with tooling and manufacturing set-up tend to be high compared to the basic design costs. Further, by their nature, such products are generally directed to a diverse market, and market introduction costs are thus significant. For these reasons, basic R & D, defined as above, may represent as little as 15% of total start-up cost.

(b) Other products, generally of greater complexity, involving more assembly operations, and often being made to order, have a different cost build-up. They are often made in facilities adapted to a variety of products which meet different needs of the

communications industry, but which have many manufacturing features (e.g. printed circuit boards in shelves on bays) in common. R & D for these products may be 50% of total start-up costs.

Cost of R & D as a Function of Sales

(a) Here again, there are no generally applicable rules. Production-line techniques are justifiable only for high volume sales, and it follows then, from the discussion above, that the costs of R & D will be low in relation to sales volume. In practice, as little as 1% of sales may be adequate.

(b) Job shop type products generally are aimed at a less diverse market, often being designed for a community of communications users rather than for individuals. This tends to limit their potential sales and raise the amount of R & D compared to sales. R & D costs may, for these products, be as high as 8% of sales.

Economics as a Factor in R & D Decisions

The decision to produce or not to produce a given item is based on a complex array of factors. The decision to manufacture a major product line, and the decisions governing the selection of individual products within that line, require judgement on economic factors as well as on purely technical ones.

The "technical" parometers, for system or sub-systems, are generally amenable to precise measurement and specification. Economic factors are quantifiable but often not to the same degree of accuracy. In spite of this, a great deal of attention has been devoted in recent years towards generating systematic decision making where subjective judgments are assigned a fixed commercial value. Procedures have been developed in which estimates of innovation costs, manufacturing costs and overhead, and marketing expense, are considered along with estimated revenues to arrive at a return-on-investment figure. These accounting tools are also applicable to the measurement of R & D progress.

Summary

In the Communications Industry,

(i) R & D costs range from 15% to 50% of total innovation (start-up) costs for new products.

(ii) a) R & D costs range 1% to 8% of probable sales of new products. b) Total Innovation costs range from 5% to 20% of the sales of new products.

(iii) The decision to undertake or not to undertake a new product venture is based, in an increasing number of cases, on a methodology which ascribe values to the cost of R & D and the possible or potential pay-off from incurred R & D expense.

Source: Dr. R.R. Jackson, Northern Electric Company Limited.

Appendix S

How Companies carry out R & D programs in Canada

A description of how industrial R&D Programs in the communications field are organized and carried out in Canada must take into account that the procedures may vary depending on size of company and ownership. Chart 1 gives a generalized view of the most likely responsibilities for the main functions associated with any R&D programs or project. There are, of course, large companies both Canadian and foreign owned, which do little or no research and development, since they depend almost entirely on imported technology to provide the design and manufacturing information for their manufactured products. On the other hand, there are large foreign-owned companies which carry out in Canada all the R&D and manufacture associated with certain lines of product for their whole company and for which they have access to world markets.

Origin of Ideas:

The main elements of any new program are origin of ideas, planning, approving and execution. In large companies, the flow of ideas, proposals, and plans is generally upward through the organization, whereas in a small company it is usually downward from the senior officers. In large companies the motivation to establish new programs comes from middle management which is sufficiently senior to appreciate the significance of ideas generated elsewhere because it is close to the technical aspects of the business. In small Canadian owned companies, the president or one of his senior officers is generally the prime innovator and motivator. Small foreign-owned companies generally do not have R&D programs, since most, if not all, of their design information is imported.

The industrial innovative cycle, leading to the introduction of new products or services, begins when an idea occurs for a mission-oriented basic or applied research program, or a carefully aimed development program. Such ideas originate from many sources, including customers, management or marketing departments, or from individual inventors either within or without the organization. Generally speaking, however, most ideas for products, services or programs originate, in large companies, in scientific or engineering departments where highly developed technological awareness of the state-of-the-art exists. At one time it was thought that innovation followed an orderly progression from research, through development to manufacture, ending in the sale of products or services. This sequence is true in many cases, but it is becoming increasingly evident that a more common starting point in industry is the recognition of a customer need. Since industry is customer oriented, R&D programs

are generally undertaken in areas where definite needs, however tenuous, have been identified.

Program Plan:

The next step is a program plan in which technical, economic, human and physical factors are considered collectively. Where the products or services are complex, it may first be necessary to institute an exploratory program to determine technical feasibility before a full development program is undertaken. Before development begins the program plan must have considered the chances of success or the risk of failure. This involves determination of the estimated total cost of the engineering development, the estimated market for the goods or services, an assessment of the capital expenditures required for tooling, testing, other manufacturing costs, cost of production prototypes and field trials and costs of market introduction. The estimated price and quantity of the product to be sold gives the estimated income which is then compared to the total of all costs up to the "ready for manufacture" point, to determine the return on the investment. Only after this is done can the risk be weighed and a decision made whether or not to proceed with the development. Decisions to carry out small developments are often made intuitively by experienced managers, but large developments where the risks are very high, are demanding more and more careful study before authorization and approval.

The program plan must take into account technical, management, marketing, financial and manufacturing aspects of the proposed program. The technical plan sets the technical objectives to be attained as a result of the development; the estimated time, staff and cost on the basis of arriving at certain milestones in order to accomplish the final objectives. Estimating some development plans is equivalent to planning invention, where success requires the solution of problems for which there is no ready solution. The tendency is to underestimate the length of time required to obtain these solutions. Experience in development work is essential in estimating realistic schedules. The management plan usually shows the organization required to perform the various tasks, including staffing, scheduling, flow or PERT diagrams. Marketing plans describe the potential markets and quantities for the successful product, including customer data, timing, sales and distribution methods, sales promotion and advertising. They may also include installation planning maintenance and servicing methods and routines. Financial Planning will depend on the size of the company. In large companies, even major programs may be fitted into the overall R&D budget. Small companies may have to borrow through normal channels, sell bonds or stocks or otherwise find financial backers. Many companies rely heavily on government incentive programs to fully or partially fund R&D

expenditure. Companies expanding their R&D operations (increasing expenditures) are usually eligible for IRDIA grants allowing them to undertake programs which otherwise could not be afforded. Manufacturing plans must take into account capital expenditure for tools, test equipment and other plan facilities which would be necessary to carry out manufacture if the product is successfully developed. These plans may also include staffing requirements, the provision of special skills, training programs, and shop loading for planned delivery scheduling.

Financial Approval:

Most industrial companies have an overall R&D budget which is approved on an annual basis by the president and board of directors. This budget blocks out the general nature of the work to be performed and the funds and staff required. During the year each major project will be studied and planned as outlined earlier and will require separate approval (within the overall budget) at different management levels up to and including the president and in some cases the Board of Directors. Smaller projects are carried out under blanket approvals in the overall budget and are individually approved at lower levels in the company.

Some foreign owned companies in Canada operate in an autonomous manner with full control of approval of their R&D programs. However, most subsidiaries refer their R&D , manufacturing and sales budgets to their parent company for approval. Major R&D projects may require corporate headquarters approval, based on a complete cost assessment by the local organization. In programs involving a high degree of uncertainty and financial risk, the usual procedure is to plan and approve only the initial expenditure, which may cover exploratory research or development or system engineering studies. When this portion has been completed, the company should have a much clearer view of the whole program and at this time decide whether or not it is worth proceeding.

The Innovation Process:

Once approval has been obtained for the entire program, research or development begins according to the technical plan. As work progresses, and designs or methods evolve, a continuous procedure of feedback and checks must be made to ensure that the desired specifications are being met. Flexibility must also be maintained so that changes in state of the available technology or customer requirements, or design changes to reduce cost or permit ease of munufacture, may be readily and smoothly introduced from time to time. This flexibility does not always exist and its absence can significantly affect the profitability of the program.

The technical feasibility phase may be considered complete when a working prototype (or breadboard) successfully meets all design criteria. However, at this stage the development is far from complete because final production models must be produced from sets of manufacturing drawings. Before this can be done, tool design and manufacture is often required in order to produce tool made samples or prototypes representative of the product to be manufactured in quantity. The cost of this portion of the development, up to the "ready to manufacture" point which includes preparation of final manufacturing drawings and related information, is generally much more expensive than the original technical development. If market studies and introduction costs are included, the total cost of the entire innovative cycle may be anywhere from two to six times the cost of the basic R&D, where R&D refers to all costs up to and including provision of manufacturing drawings.

Exploratory Work:

Before technical feasibility can be demonstrated, exploratory development or even basic research may be required. If neither of these activities is involved, the project would be simply a matter of engineering design based on known techniques or principles. Design programs should in no way be downgraded, since they are a primary source of innovation and contribute heavily to the promotion of new business. New R&D is not always necessary to create innovative programs, since a vast store of knowledge derived from past R&D activities now exists and can be used for many years to come.

Development:

During the development of a product or the evolution of a product design, feedback to the designer from company departments which will later be affected is one of the most important procedures required to attain success. Tool and test-set design and manufacturing departments have essential information concerning the effect of design details on production costs; marketing may contribute information which will effect the acceptability of the product. Installation departments can often offer suggestions to the designer which will lower installation and maintenance costs. Where the development effort is spread over several years, it is also important to keep in close touch with the potential market because requirements may change from year to year. Many development programs have been less than fully successful because this reevaluation mechanism either did not exist or was ignored.

In many instances this feedback process exists throughout the life of a product and adds considerably to the cost of maintaining the product in production. Sometimes

maintenance is referred to as "product,improvement and evolution". The cost of maintaining a product with long life is really part of the development cost and is the cost of postponing the obsolescence of the product. It is seldom included in the original estimates of R&D costs because the future of any product is difficult to foresee over an extended period of time.

Development is a process whereby a product design is created:

(a) directly by the designer's knowledge and experience,
(b) by mathematical calculation as a direct or indirect method of arriving at decisions affecting the size, shape, function, materials, etc. to meet design requirements.
(c) by systematic cut and try methods.

The process usually requires the solution of one succeeding problem after another, trade-offs between performance and cost and between one criteria and another until all essential problems can be resolved, this means that all designs (certainly in the communication field) should be optimizations of performance characteristics and cost.

In addition to skill and knowledge, development work demands certain human characteristics and temperment. People who are easily discouraged, who lack tenacity and drive seldom make good developers. Ability to absorb, mould and use the results of work done by others is essential. The developer should be co-operative by nature. He needs to have courage, imagination and stamina, especially on programs extending over many years.

Manufacturing Design:

When a prototype which can demonstrate the feasibility of meeting all design requirements has been designed and built, the work of producing a manufacturable design begins. The cost of this part of the process, up to a complete set of manufacturing drawings and full manufacturing information (including manufacturing specifications, tool design, making and prove-in , provision of capital equipment, floor layouts, process design and implementation, etc.) is at least equal to, and usually much greater than the cost of the basic design for proving feasibility. It is generally necessary to produce tool-made samples of the product to prove-in tooling and shop processes and methods. Depending on the nature of the product, field trial models may be necessary to check the design under actual field operating conditions and also to test customer acceptance. During production of such models and the field trial period, customer feeback to the designer is essential so that

mandatory changes may be made to the original design or manufacturing methods.

Assessment of the final results of the field trials by the original designers or planners must take place before final approval is given to proceed with production.

Appendix T

The Generation and Control of Ideas

in Research and Development

The title suggests a paradox, and Webster defines a paradox as "an assertion seemingly contradictory, or opposed to common sense, but that yet may be true in fact".

The complexity of any organizational structure is a function of its size, and a large Corporation engaged in Research and Development is faced with two major problems:

(1) How to ensure the continued generation of new ideas within a framework of sound economic control.

(2) How to communicate rapidly and accurately between the many segments of the organization which have had diverse backgrounds of experience and as result of which have different expectations of what constitutes success.

In a nutshell the problem is how to ensure that the various arms of the Marketing, R&D, Engineering and Manufacturing departments will all be enthusiastic about the same project at the same time, and that the project will turn out to be an economic success.

The answer appears to involve the creation of an informal atmosphere of inter-departmental team effort at all levels throughout the organization, working within a well conceived formal organizational structure, with well defined areas of responsibility and well recognized methods of communication.

Within the Bell Canada Ltd/Northern Electric Co Ltd. organization, various tools are employed in an attempt to reach both those objectives.

Due to the rapid pace of technological change and due to the rapidly changing external environment, much time and effort is devoted to the determination and understanding of a set of <u>dynamic corporate objectives</u>.

All R&D activity is logically divided into three broad time frames:

(1) Planning
(2) Feasibility testing

(3) Development.

Planning

R&D systems engineering is responsible for network definition within the territory served by Bell Canada. This involves the identifications of new products required to permit handling existing services more economically, the introduction of new services to increase usage of the existing network, and anticipation of the change required to be able to cope with future service requirements that could exceed either the capacity or the capability of the existing network design.

During the planning phase systems engineering works in close cooperation with the Bell H.Q. Planning and Design divisions in order to determine the future market and operating and maintenance requirements of the operating company and with the Marketing departments or the various manufacturing product divisions in order to determine and influence the business plans of those divisions.

The output of the planning phase is called a Prospectus, a document which delineates what should be done and why it should be done.

The factors considered in the preparation of a Prospectus include:

(1) Corporate Objectives.
(2) The Need -- The need is basically established by the users of telephone service, not by the company providing the service, and certainly not by the manufacturer of the products required to provide the service.
(3) The Market -- The extent of the need is determined through the preparation of short and long term market surveys.
(4) The State-of-the-Art -- The State-of-the-Art proposed to be used in a new development versus the general State-of-the-Art has significant impact on the anticipated life of any new product.
(5) The Competitive Situation -- The contemplated availability of competitive offerings has significant impact on the availability of a short term market.
(6) Availability of Resources -- The availability of resources to develop, to manufacture, and to sell has an important bearing on the advisability and timing of introduction of each new product.
(7) Economic Feasibility -- Various ratios of Development and Start-up cost to anticipated sales dollars, anticipated cost price ratios and discounted cash flow

studies are used to evaluate the relative economics of various projects.

(8) Technical Feasibility -- The degree of confidence in being able to meet the requirements of the need must be estimated.

(9) Timing -- Each of the above factors is time sensitive and so the overall timing must be worked out on the basis of an optimum compromise.

Feasibility Testing

Assuming that the recommendations contained in the prospectus are agreed to by Bell, by the Manufacturing Product Division, and by the appropriate development group in R&D an exploratory development program is initiated to test the technical and economic feasibility of the recommendations contained in the prospectus. At the same time the Product Division Marketing department undertakes a detailed market analysis to establish realistic price and sales objectives.

During the exploratory development phase systems engineering works in close cooperation with the development group to refine the product definition.

The output of the feasibility testing phase consists of a definition of system requirements from the Systems Engineering group, an estimate of costs and a plan from the development group, a set of market objectives from the Product Division Marketing group and an estimate of startup cost and manufacturing costs from the Manufacturing Division.

All this information is analysed by a Product Planning Committee consisting of representation from Systems Engineering, Development, Marketing and Manufacturing and a recommendation in the form of a Product Development Authorization is forwarded for approval by the Vice President of the Product Division or by an administration committee consisting of the Vice-President R&D, Vice-President Engineering of Bell and the Vice President H.Q. Planning of Northern Electric.

Source: Northern Electric Company Limited.

Appendix U

Notes - re Need for Research in Fields other than Pure Technology

The future is becoming more important to the present than it has ever been: we have entered an era where the pace of change is accelerating so rapidly that man has difficulty in reacting with appropriate speed and responses. At the same time the scale of impending change is increasing. Therefore, the risks and opportunities that confront us justify expanded efforts to lead the course of events rather than be led by them.

Long-term planning, which is the art of optimising the consequences of future probabilities when deciding what to do today, is used to various extents in conventional public and private institutions. Too often such planning is in no way geared to this task. Even more unfortunately, the effort is all too frequently highly-oriented to future technological possibilities without regard for society's real needs and emerging patterns of living.

The challenge to policy-makers and planners in public and private enterprises is to develop a true understanding of the underlying causes and needs behind society's propensity to generate forces of change. Such study is needed to give proper direction to any technological developments. Now , almost anything can be invented and developed. The question is what does society really need?

An illustrative example of the range of problems is reflected in the telecommunications industry. Historically, this industry has been involved in long-term planning because its very existence depends on providing service on demand, where and when customers want that service. Providing service requires much fixed capital investment. Hence, planning must correctly anticipate what man needs and where he is likely to want it.

Within recent years, Bell Canada, has augmented its long-term planning effort with an environment-study process. This was introduced in' the belief than many forces exist, are developing, or are waning, all of which make the future look a lot different from a mere statistical extension of past and present trends.

The guiding philosophy of the environment-study process is that man is the key to what happens in the environment. He, alone among living creatures, not only accommodates to the limits of his environment but simultaneously attacks and seeks to overcome these limits, motivated by his capacity and desire to picture and fashion an improved condition of life. His environment influences him, but he in turn influences it.

Man's development and his destiny become a continuing process of action and reaction. These forces interact through economic, political, social, philosophical and technological aspects of the environment. The results of these interactions are man's constructions (urban landscape) and institutions. Therefore, for a better understanding of the future landscape and institutions it becomes necessary to analyse man himself, and how he has reflected his desires in his present constructions. These constructions are of particular concern to the telecommunications industry since its service is provided by 'overlaying' what man builds. On the other hand, well planned communications systems designed to meet new and emerging needs can in turn influence how man may wish to shape his physical, social and economic environment. For instance, to be able to go to the office by staying home is becoming an increasingly viable option.

Many organizations have a very large stake in understanding such problems. Governments are concerned, so that they may enact laws which would control potentially undesirable situations. Industry is or should be vitally concerned with these problems. All organizations that must distribute services to the population are concerned with how and when cities will grow. Manufacturers are concerned with how markets will shift geographically, how tastes will change, and what new responsibilities they must share with society. Similarly, universities, over and beyond concern for how changing environmental factors will affect them, are increasing their study of the various aspects of the environment. For example, the University of Toronto has a centre for Urban and Community Studies, and the University of Waterloo has initiated a Department of Man-Environment Studies. In addition, CMHC. is offering 125 fellowships for graduate research in the urban environment and related topics. All these examples and many others indicate a large concern for the problems of man and his environment.

As these concerns grow, research by individual organizations will increase. This could result in a gross misuse of resources, since much of the research would possibly be duplicated and all available data and views would not be available in any one place. Moreover, certain companies may have data bases available that would be of immense value to the country in general.

At the present time TCTS, through Bell Canada, is attempting to overcome some of these problems by organizing studies between industry and universities. For the past three years Bell Canada has worked with the University of Toronto on studies concerned with such subjects as central city, urban-rural trends, urbanization, transportation, housing, to name a few. These studies have proven to be very profitable to both

organizations. In 1969 studies between Bell Canada and the University of Montreal were initiated to pursue topics such as Cellular Design of Living and Working Spaces, Urban Accessibility, Changes in the Nature and Functions of Centre-City, Residential Trends and Shopping trends. These industry-university studies consist primarily of papers on the various subjects and will provide the bases for several seminars in the near future. So far, within Bell Canada, exploratory thinking on changing social, economic, and philosophical patterns is largely in the hands of a few people who rely on conferences, reading, and academic contacts for mutual stimulation and direction.

While other examples of work on component subject areas are presently being performed in many institutions, a sufficiently concentrated and interdisciplinary integrated activity with the necessary skills, scope, and freedom does not exist in Canada to-day. The time seems ripe to consider the setting up of a group, possibly a national cooperative foundation, which could undertake fundamental studies and examine long-term consequences of decision contemplated to-day that would affect all aspects of environmental problems - urban, regional and national. Indeed the complexity of inter-relationships among the various sectors of modern society makes inter-disciplinary analysis a necessary precondition to the effective function of such an organization. Such a foundation would provide an effective way for industry, government and educators to pool resources and effectively tackle problems facing Canada, as well as providing planners with the information to suggest means of creating a better way of life.

Source: Bell Canada Limited.

Appendix V

A New Research Relationship

The Environment Study is attempting to improve our Company's planning ability at two levels: one is the long range work to the year 2000, with an emphasis on trends rather than numbers; the other level concentrates on the next ten to fifteen years. It is hoped that we can achieve an understanding of present inter-relationships and trends which will contribute to a predictive model for the two time periods. It is anticipated that for the longer term it will be necessary to combine mathematically oriented forecasting methods with intuitive speculation.

A unique research relationship between Bell Canada and the University of Toronto has resulted in a significant contribution to our Company's planning potential. As a link between theoretical and pragmatic research, this liaison is providing significant input to the Environment Study.

During 1966 and 1967 the basic concepts of the Environment Study evolved, and a fundamental framework was presented to the University of Toronto. This framework formed the guidelines according to which the University has operated ever since.

For the first year, 1967-68, it was mutually agreed that the University would undertake several main areas of research, including study of urban patterns and trends, comparison of US and Canadian city structures and rural land use changes. By the end of 1968 we had received nine reports and four seminar papers.

During the second year, 1968-69, the urban and rural studies were continued, and several new areas were opened up. Exploration began into (1) the characteristics of the rural-urban "fringe" known as the urban field; (2) transportation and its impact on land use; (3) the role of migration and interaction in creating urban patterns; and (4) various forecasting methods. To date (December 1969) we have received eleven reports and we are expecting another five before January 1970.

The proposal for the third (and current) year, 1969-70, extends the foregoing studies, with the exception of forecasting methods, which will be expanded only in 1971-72 when data from the other studies can be collated and used as input for a predictive model.

The concept of the Environment Study evolved gradually over a period of years until in 1967 its main precepts could be put onto paper. Similarly, Toronto's contribution is evolving

and developing as the researchers benefit by new insights into the whole problem of the changing environment.

1967 - 1968 Studies
University of Toronto

Report No.	Title	Author	Date Received
1	Urban Development, Ontario and Quebec: Outline and Overview	L.S. Bourne & A.M. Baker	Sept. 1968
2	Behaviour of the Ontario-Quebec Urban System: City - Size Regularities	J.B. Davies & L.S. Bourne	Sept. 1968
3	Structural Characteristics of the Ontario-Quebec Urban System	T. Bunting & A.M. Baker	Sept. 1968
4	Growth Characteristics of the Ontario-Quebec Urban Systems	S. Golant & L.S. Bourne	Sept. 1968
5	Trends in Urban Redevelopment	L.S. Bourne	Sept. 1968
	Appendix - List of Cities and Urban Development Variables		
6	Flows in an Urban Area: A Synthesis	J.W. Simmons	Nov. 1968
7	Farm Numbers in Ontario and Quebec Analyses and Preliminary Forecasts	E.B. MacDougall	Sept. 1968
8	Trend Surface Analysis of Farm Size Patterns in Ontario and Quebec 1951-1961	G.T. McDonald	Sept. 1968
9	Comparisons of Structure and Growth of Urban Areas in Canada and the USA	Gerald Hodge	Mar. 1969

Seminar Papers - Urban Field (Sept. 1968)

1	The Urban Field of Toronto: An Examination of a Sector	Heather Heaps	
2	New Parameters in Rural Land Subdivision	M.E. Kusner	

3	The Distribution and Impact of Cottagers in Toronto's Urban Field	A.P. Hammer	
4	Travel Patters	R.J. Gravel	
Report			
10	Land Use Structure and City Size An Ontario Example	C.A. Mather & L.S. Bourne	Feb. 1969
11	Cartographic Summary of the Growth and Structure of Cities in Central Canada	G. Gad & A. Baker	Mar. 1969
12	Univariate Spatial Forecasting	L. Curry	Sept. 1969
13	Dynamic Programming and Geographical Systems	R. MacKinnon	Aug. 1969
14	Forecasting Land Occupancy Changes Through Markovian Probability Matrices: A Central City Example	L.S. Bourne	Aug. 1969
15	Models of Spatial Behavior in Urban Areas	A. Baker	Sept. 1969
16	Urban - Rural Relationships	R. VanderLinde	Nov. 1969
17	Structure & Process in Small Urban Areas	G. Barber &	Oct. 1969
18	Highway System of S.Ontario & Quebec: Network Generation Problems	R. Mackonnon	
19	A Highway Link Addition Model for S. Ontario	J. Hodgson	Nov. 1969
20	Space as a Variable in Seriological Enquiry	W. Michelson	Nov. 1969
21	Analytic Sampling for Design Information.	W. Michelson	Nov. 1969

The research relationship which has existed since 1967 with the University of Toronto and was extended to include the University of Montreal in 1969.

Discussions through 1968 and the first half of 1969 formed the basis of a mutual agreement in September 1969 whereby Professor Chevalier is responsible for a program of research on our behalf. The Faculte d'Amenagement, for which he is in charge of graduate studies, includes architecture, urbanism, and industrial design which together form the Faculty.

The proposal which we agreed upon outlines five main areas of interest:

(a) Cellular design of living and work space
(b) Design for urban accessibility
(c) Changes in the nature and functions of centre city
(d) Residential trends; and
(e) Shopping trends

Of these work is actively progressing in part (b) - urban accessibility: as a study of the need for school space in centre city and the concomitant inefficient use of space in the central city.

The Study on cellular design is already underway under other auspices.

The work that the University of Montreal is undertaking is different in scope than that of the University of Toronto. It is much more problem oriented, due in part to the influence of Michel Chevalier, and less concerned with exploring casual relationships as is Toronto.

It follows that our involvement with them has also differed from our relationship with the University of Toronto. We are being asked for much greater participation not only for ideas, but also as consultants to them as to communications possibilities.

Source: Bell Canada Limited.